Influence of Chaining Pinyon-Juniper on Watershed Values in Utah

Project Report

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Utah Agricultural Experiment Station
in cooperation with
Bureau of Land Management

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Title of Study: Effects of Pinyon-Juniper Conversion on Watershed Values in Utah

Objectives:

A. To determine the water budget of natural stands of pinyon-juniper and adjacent areas which have been cleared and/or seeded.

B. To determine the effects of vegetation conversion on soil physical properties and soil stability.

C. To ecologically evaluate sites before and after as to composition and production of vegetation.

D. To evaluate the economics of conversion practices in terms of the watershed values and multiple use relations.

E. To obtain data necessary for determination of hydrologic soil cover complexes on the study sites.

Introductory Comment: This report is concerned with additional data analysis and compilation which has resulted since the project report dated April 1, 1972. As before, the report will provide information to supplement previous reports as well as indicate progress to date.

Runoff Plot Studies: No runoff events occurred at either site during 1972.

Tables 1, 2, and 3 give precipitation data from the Blanding study site. Conditions at the Blanding site were dry until 10-4-72, which was the start of a moist period. Significant amounts of moisture occurred during the period 10-4-72 to 10-20-72 (Table 1). Runoff plots were shut down about 10-1-72, however, examination of the 1-foot type HS flumes for high-water lines on each runoff plot following the rainy period revealed that flow rates from the plots were so minimal as to hardly have

Table 1. Precipitation data from 8-inch recording gages at Blanding study site, 1972.

Date	Total Rainfall (inches) Windrow Area	Total Rainfall (inches) Debris-in-Place
6-8-72	Start	Start
6-22-72	No Record	0.78
7-19-72	0.35	0.35
7-21-72	0.21	0.20
7-24-72	0.13	0.12
7-25-72	0.13	0.16
8-14-72	0.16	0.18
8-19-72	0.33	0.44
8-25-72	0.07	0.06
9-5-72	0.09	0.12
9-6-72	0.36	0.39
9-7-72	0.04	0.03
9-19-72	0.50	0.56
10-4-72	1.36 (over 16 hours)	1.39
10-7-72	1.13 (over 9 hours)	1.14
10-12-72	0.24	0.20
10-15-72	0.86 (over 16 hours)	0.88
10-16-72	0.14	0.10
10-17-72	0.34	0.31
10-18-72	0.62 (over 12 hours)	0.70
10-19-72	1.13 (over 24 hours)	1.10
10-20-72	0.96 (over 5 hours)	0.86
10-23-72	Stop -- Storage gage charged	

Table 2. Precipitation data from 8-inch nonrecording gages at Blanding, debris-in-place area, 1972.

Date	Total Rainfall (inches)	
	Gage A [1/]	Gage B
6-8-72 to 6-23-72	0.77	0.68
6-23-72 to 7-10-72	0.00	0.00
7-10-72 to 7-20-72	0.37	0.36
7-20-72 to 8-2-72	0.46	0.43
8-2-72 to 8-19-72	0.56	0.59
8-19-72 to 8-31-72	0.13	0.11
8-31-72 to 9-12-72	0.56	0.54
9-12-72 to 9-22-72	0.55	0.54
9-22-72 to 10-24-72	6.93	6.84

[1/] Located next to recording raingage.

Table 3. Precipitation data from 8-inch nonrecording gages at Blanding, windrow area, 1972.

Date	Total Rainfall (inches)	
	Gage A 1/	Gage B
10-11-72 to 2-26-72	2.19 2/	
2-26-72 to 4-13-72	0.00 2/	
4-13-72 to 6-8-72	0.90 2/	
6-8-72 to 6-23-72	0.80	0.74
6-23-72 to 7-10-72	0.00	0.00
7-10-72 to 7-20-72	0.34	0.35
7-20-72 to 8-2-72	0.50	0.44
8-2-72 to 8-19-72	0.43	0.61
8-19-72 to 8-31-72	0.12	0.13
8-31-72 to 9-12-72	0.49	0.59
9-12-72 to 9-22-72	0.54	0.55
9-22-72 to 10-24-72	6.93	6.75
10-24-72 to 12-2-72	2.40 2/	

1/ Located next to recording raingage.

2/ Only the storage gage was maintained during these periods.

Table 4. Precipitation data from 8-inch recording gages at Milford study site, 1972.

Date	Total Rainfall (inches)	
	Windrow Area	Debris-in-Place
6-6-72	Start	
6-7-72	0.19	Start
6-8-72	0.03	0.04
6-22-72	0.33	0.34
7-9-72	0.02	0.05
7-26-62	0.07	0.07
7-31-72	0.07	0.10
8-1-72	0.00	0.05
8-11-72	0.03	0.04
8-13-72	0.28	0.28
8-14-72	1.20	1.19
8-15-72	0.05	0.05
8-18-72	0.20	0.20
8-19-72	0.07	0.06
8-26-72	0.03	0.03
8-27-72	0.48	0.50
8-28-72	0.03	0.02
9-1-72	0.08	0.07
9-3-72	0.13	0.13
9-6-72	0.03	0.00
9-7-72	0.02	0.00
9-18-72	0.30	0.25
9-19-72	0.46	0.32
10-1-72	Off -- Storage gage charged	

Table 5. Precipitation data from 8-inch nonrecording gages at Milford, debris-in-place area, 1972.

Date	Total Rainfall (inches)		
	Gage A [1/]	Gage B	Gage C
6-6-72 to 6-20-72	0.22	0.25	0.24
6-20-72 to 7-7-72	0.38	0.33	0.37
7-7-72 to 7-22-72	0.07	0.06	0.04
7-22-72 to 8-5-72	0.20	0.17	0.13
8-5-72 to 8-20-72	1.89	1.97	1.85
8-20-72 to 8-29-72	0.51	0.49	0.52
8-29-72 to 9-10-72	0.22	0.23	0.30
9-10-72 to 10-1-72	0.61	0.57	0.52

[1/] Located next to recording gage.

Table 6. Precipitation data from 8-inch nonrecording gages at Milford, windrow area, 1972.

Date	Total Rainfall (inches)		
	Gage A 1/	Gage B	Gage C
10-6-72 to 2-18-72	2.48 2/		
2-18-72 to 4-1-72	0.00 2/		
4-1-72 to 6-6-72	1.71 2/		
6-6-72 to 6-20-72	0.24	0.21	0.20
6-20-72 to 7-7-72	0.34	0.35	0.30
7-7-72 to 7-22-72	0.00	0.01	0.00
7-22-72 to 8-5-72	0.19	0.13	0.15
8-5-72 to 8-20-72	1.87	1.86	1.81
8-20-72 to 8-29-72	0.55	0.40	0.51
8-29-72 to 9-10-72	0.29	0.40	0.27
9-10-72 to 10-1-72	0.74	0.65	0.71
10-1-72 to 10-19-72	1.71 2/		

1/ Located next to recording gage.

2/ Only the storage gage was maintained during these periods.

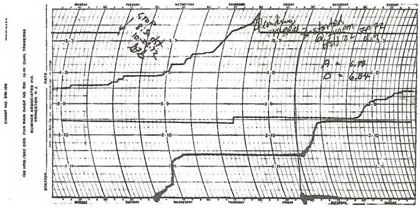


Figure 1. Chart tracing from 8-inch recording raingage at Blanding study site showing rainfall during the period 10-4-72 to 10-20-72.

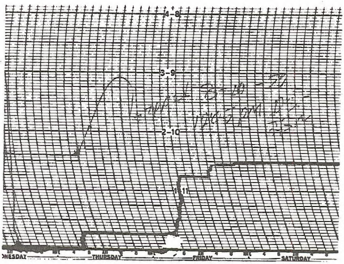


Figure 2. Chart tracing from 8-inch recording raingage at Milford study site showing rainfall during the period of 8-13-72 to 8-15-72.

been detectable. This undoubtedly resulted due to the very low intensities of the rainfall (Table 1). Some idea of the low rainfall intensities during the wet period can be had by referring to Figure 1.

Table 4, 5, and 6 give rainfall data from the Milford study site. Conditions at Milford were dry, with only one potential runoff-producing storm occurring on 8-14-72 (Table 4, Figure 2). Rainfall intensities were not sufficient enough, however, to cause any significant overland flow.

Runoff and sedimentation data from all 5 years have been analyzed and a manuscript prepared. The manuscript, entitled "Runoff and Sediment Yields from Runoff Plots on Chained Pinyon-Juniper Sites in Utah", has been accepted for publication. A copy is included in Appendix 1.

Soil Moisture Studies:

Milford and Blanding. Soil moisture data from the Milford and Blanding study sites have been analyzed, a manuscript prepared, and the manuscript has been accepted for publication. A copy of the manuscript, entitled "Soil Moisture Patterns on Two Chained Pinyon-Juniper Sites in Utah", can be found in Appendix 1.

Sap Velocity Studies:

Studies designed to give a preliminary look at water use by Utah juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus edulis*) have been completed and data have been analyzed and a manuscript prepared. The manuscript, entitled "Sap Velocities in Pinyon and Juniper Trees and Their Relationship to Measured Environmental Factors", is included in Appendix 1.

Runoff Curve Numbers

Runoff curve numbers have been computed for all runoff plots for all storms, and are given in Appendix 2. The data are useful, but average values representing all plots within a given treatment are probably much more realistic. Average curve numbers for the storms studied are given below:

Milford

Control (Woodland)

	P	Q	CN
7-30-68	1.65	0.77	89.4
7-31-68	0.60	0.12	91.2
8-8-68	0.70	0.02	80.9
9-5-70	1.47	0.07	69.5

Windrow

	P	Q	CN
7-30-68	1.65	1.27	96.4
7-31-68	0.60	0.19	93.7
8-8-68	0.70	0.07	86.0
9-5-70	1.47	0.12	73.0

Blanding

Control (Woodland)

	P	Q	CN
7-28-68	0.45	0.02	88.0
7-30-68	0.45	0.03	89.2
8-5-68	1.45	0.42	85.0
8-3-70	1.27	0.05	71.5
8-4-70	0.81	0.12	86.5

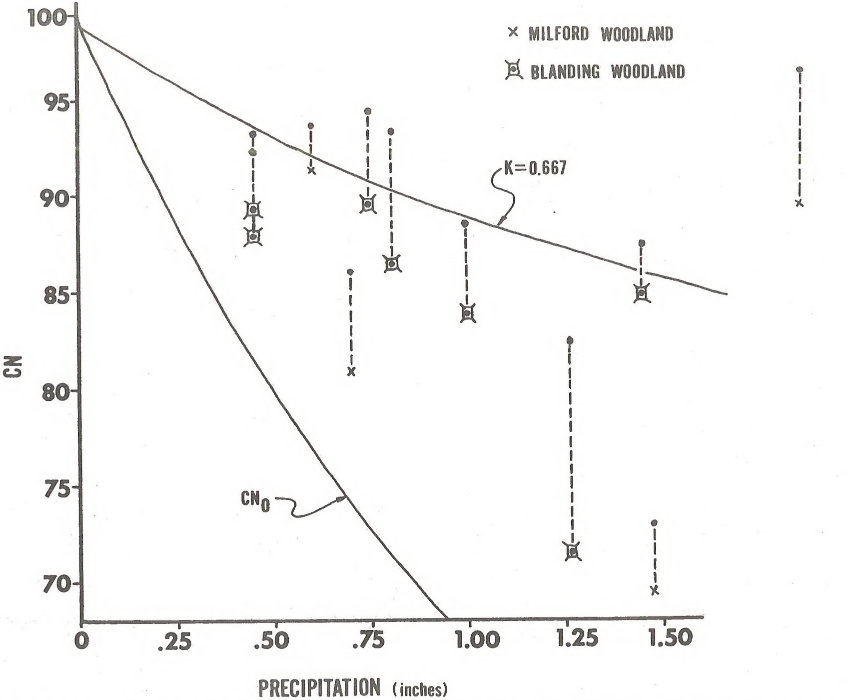


Figure 3. Relationship of CN to total storm precipitation. The single dots represent average values from the windrowed treatment at either Milford or Blanding. The "K" coefficient is derived from data from the windrowed treatment at Blanding, and represents only one of four possible "K" values which could have been plotted (see text for further explanation).

8-16-70	1.00	0.15	83.9
8-19-70	0.75	0.16	89.6
Windrow			
7-28-68	0.45	0.07	92.2
7-30-68	0.45	0.09	93.2
8-5-68	1.45	0.52	87.4
8-3-70	1.27	0.25	82.4
8-4-70	0.81	0.32	93.3
8-16-70	1.00	0.27	88.6
8-19-70	0.75	0.32	94.3

There is some indication (Figure 3) that the curve numbers are not independent of total storm size (Hawkins, unpublished data). Drawing from experiences on small watersheds elsewhere in the state, it may be suggested that curve numbers be estimated from the expression

$$CN = \frac{2 + KP}{2 + P} (100)$$

where P is storm size (inches) and K is a coefficient characteristic of the watershed. Studies by Hawkins (unpublished) indicate that "K" is a more stable index of a watershed's hydrologic behavior than the customarily used curve number. Values of "K" in these plot studies are given below (determined from the field data and a least squares solution of the above equation):

<u>Milford</u>

Control (Woodland)	K = 0.510
Windrow	K = 0.639

<u>Blanding</u>

Control (Woodland)	K = 0.476
Windrow	K = 0.667

A more thorough explanation of the use of this concept is given in Appendix 1 in a preliminary manuscript entitled "Improved Prediction of Storm Runoff in Mountain Watersheds" by R. H. Hawkins. Comments regarding the manuscript should be directed to Dr. Hawkins, Watershed Science Unit, College of Natural Resources, Utah State University, Logan, 84322.

Economic Evaluation of Range Conversion Practice In Terms of Multiple Use Benefits

Current Status: Natural resource managers and planners in the federal agencies are increasingly faced with the problem of economically justifying improvement projects. No longer can federal projects be justified on the basis of "need" alone.

Often in the past, projects have been justified and implemented on the basis of a single benefit or use. This is no longer adequate for most agencies for four reasons: (1) many projects are not economically feasible when considering only a single benefit, (2) competition among different federal agencies for federal money is becoming more intense, (3) "environmentalists" are exerting more pressure on agency administrators, especially since the passage of the National Environmental Policy Act (NEPA) in 1969, and (4) the fact that many federal projects result in multiple benefits should be emphasized for both economic and environmental reasons.

In order to adequately determine the economic feasibility of BLM pinyon-juniper chaining projects, estimates of the benefits must be compared with the treatment costs. To obtain a correct estimate of the

total benefits that result from a pinyon-juniper chaining, it would be necessary to measure the benefits that accrue from: (1) increased watershed values, (2) increased livestock carrying capacity, (3) a more diversified or increased carrying capacity for wildlife, and (4) increased recreational uses. Increased carrying capacity for livestock is an easily measured benefit but the other benefits mentioned are difficult to quantify.

Objectives

Managers and planners involved in identifying and measuring the benefits of a project could often make use of the benefits described in environment impact statements required for either the project under consideration or for similar projects. Once the benefits have been identified, the manager or planner will have to estimate their value. It is the intent of the authors of this section to identify these benefits and to offer methods of estimating value.

Some basic research has been done in the past concerning methods of identifying and valuing the more elusive benefits. It is the intention of the authors to complete a detailed literature search to find workable methods that have already been developed and to use some of this past research to help develop new methods where necessary. It is hoped that BLM and other federal agencies will find these methods adequate for identification and measurement of project benefits and costs.

Infiltrometer Studies

INTRODUCTION:

Pinyon-juniper woodland has historically been utilized for domestic livestock grazing and much of the pinyon-juniper range was once capable of sustaining large numbers of animals. However, overgrazing, reduced occurrence of wildfires, and dispersal of seed by the grazing animals resulted in competitive advantages to the trees and they replaced the herbaceous cover on large acreages. Today we find large areas of pinyon-juniper woodland that supports little or no understory vegetation.

There is little demand for pinyon and juniper tree products. But there is a demand for the forage products pinyon-juniper dominated sites can produce. To meet this demand, vegetation modification projects have been applied to suitable areas in an effort to restore the woodland to productive grazing land.

JUSTIFICATION AND OBJECTIVES:

Williams (1969), working in the same area as the present study, found few statistically significant differences between infiltration and erosion rates on unchained (natural woodland) and chained (debris-in-place or windrowed) pinyon-juniper sites. Livestock grazing was an uncontrolled, confounding factor in all comparisons that indicated significant differences. This implied effect of grazing on infiltration and erosion rates indicated that the grazing influence on pinyon-juniper sites needed closer analysis.

Information concerning grazing impacts on infiltration and erosion rates is of practical interest because the high intensity, short duration thunderstorms that occur in the pinyon-juniper zone often produce surface runoff and cause considerable erosion. Besides causing siltation problems

downstream, excessive erosion probably reduces the productive potential of the woodland. Thus, any management practice; e.g., grazing and/or vegetation manipulation; that significantly lowers the infiltration capacity probably leads to increased erosion and deterioration of the site rather than improvement.

With these ideas in mind, the objectives of this study were:

1. Determine the effects of grazing, when compared to areas on which grazing had been eliminated, on infiltration and erosion rates of debris-in-place, windrowed, and unchained pinyon-juniper sites.
2. Utilize these measurements in developing guidelines for hydrologically sound grazing management of pinyon-juniper rangeland.

To accomplish these objectives, we found it necessary to separate the grazing impact on infiltration and erosion into forage remcval and soil compaction effects.

METHODS:

The importance of ground cover has long been stressed as an essential prerequisite in efforts to control flooding and erosional problems. Vegetation does not control runoff, but its presence does increase the hydrologic roughness which in turn slows overland flow allowing more time for infiltration to occur. Thus our hypothesis, although not expressed in a null-hypothesis manner, was that infiltration and erosion rates would vary in relation to the amount of vegetative material present on a plot. The clipping subtreatment consisted of removing 0, approximately

50, and 100 percent of the vegetative material from randomly selected infiltrometer plots. These subtreatments were sampled during June-July, 1971; August-September, 1971; and June-July, 1972.

Soil compaction has also been of interest to range managers for many years. In this instance we are referring to the packing together of soil particles by instantaneous forces exerted at the soil surface resulting in an increase in soil density through a decrease in pore space. Trampling by livestock often results in soil compaction. In fact, trampling has been accused of many things: reduced infiltration rates; reduced percolation rates; increased bulk densities; and reduced forage availability through destruction of leaves and damage to growing points. The magnitude of these effects varies with soil texture and structure, soil density, soil moisture content, organic-matter content, and amount and duration of soil freezing.

Lull (1959) discussed the detrimental effect of soil compaction on infiltration and soil stability. He reported that cattle exert static or standing loads of about 24 lbs/in^2; however, two to four times this static load can occur when the animal moves. In this study, to insure uniform compaction subtreatments between plots, a compaction frame was designed to fit the infiltrometer plot frames (Figure 4), and the same trampling "feet" were used to compact each plot. Randomly selected plots in ungrazed exclosures had 0, 30, or 60 percent of their surface area compacted with a force of 30 lbs/in^2. This force was chosen as a compromise between static and moving loads, but favoring standing conditions. Care was taken in installing and removing the frame to prevent the "feet" from causing any disturbance other than compaction.

The study was carried out during two sampling periods in 1972, June-

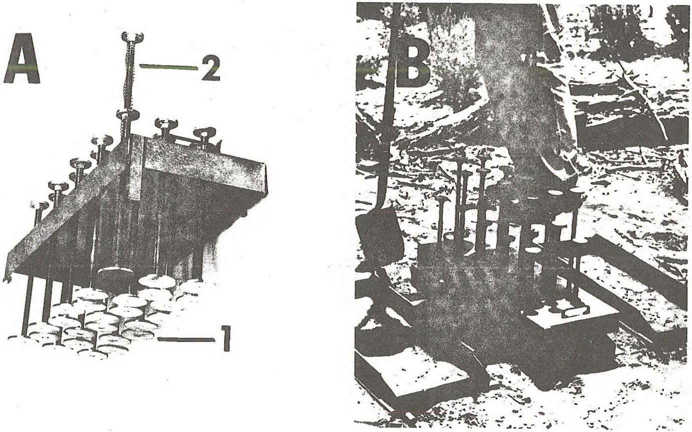


Figure 4 . Compaction frame used to compact 30 and 60 percent of the surface area of randomly selected plots (A-1). The 7.5 cm (diameter) metal "feet" that contacted the soil. All compaction disks were utilized on plots selected for the "60% compacted" subtreatment while only one-half of the disks were used on plots receiving the "30% compacted" subtreatment. Those disks not used on "30% compacted" plots were held above the soil surface as illustrated in A-2. The combination of disk utilized for the "30% compacted" subtreatment was randomly selected and applied to all plots selected for this subtreatment. B) Field installation and use of the compaction frame. The researcher steps on only one of the compaction disk at a time applying a compaction force of approximately 30 lbs/in^2.

July and August-September. A minimum of 6 replications of each trampling and intensity were used within each exclosure in each chaining treatment. Each exclosure, remember, represents protection from grazing for a given number of years. Adjacent, current grazed areas were also sampled.

Our study area is in the Colorado Plateau physiographic region near Blanding, Utah. Soils are relatively deep sandy loams, annual precipitation averages about 13 inches, the pinyon species is *Pinus edulis*, and the juniper is *Juniperus oesteosperma*. Extensive areas are dominated by these two tree species and large acreages of pinyon-juniper have been chained within the study area. We were able to obtain within close proximity the following vegetation and grazing conditions:

Vegetative and Grazing Conditions Sampled:

Chained, Debris-in-Place

- Grazed
- Grazing excluded 1967
- Grazing excluded 1969
- Grazing excluded 1971

Chained, Debris-windrowed

- Grazed
- Grazing excluded 1967
- Grazing excluded 1971

Unchained (Natural Woodland)

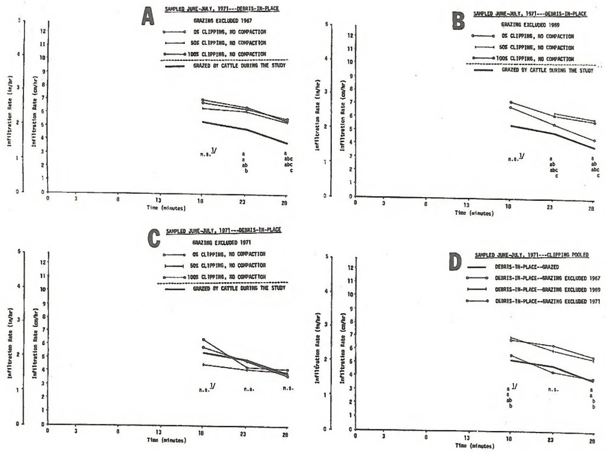
- Grazed
- Grazing excluded 1967
- Grazing excluded 1969
- Grazing excluded 1971

Our sampling technique involved simulating high intensity rainfall with the Rocky Mountain Infiltrometer. To reduce variability between plots utilized to study the forage removal and soil compaction effects, three runoff plots were located immediately adjacent to each other and clipping and compaction subtreatments randomly applied to one of the three. Following installation of the plots and application of subtreatments, various vegetative and edpahic parameters were measured, plots were prewet to reduce antecedent soil moisture effects, and a rainfall intensity greater than 3.5 in/hr was applied for 28 minutes. Infiltration, the difference between rainfall applies and measured runoff, was measured at six time intervals. Erosion, measured as the amount of soil washed from the plots, was measured at three time intervals.

RESULTS:

Results of the clipping study indicated that our hypothesis was incorrect. On chained, either debris-in-place or windrowed sites, neither the weight of vegetative material nor the percent total cover indicated a consistant or significant influence on infiltration rates.

Clipping subtreatments (equivalent to the amount of vegetation on the plots) produced no significant differences in infiltration rates on chained, debris-in-place or chained, windrowed plots (Figures 5-A,B,C; 6-A,B; 7-A,B,C; 8-A,B; 9-A,B,C; and 10-A,B). During all three sampling periods, the 0, 50, and 100 percent clipped plots sampled within each vegetative and grazing condition recorded statistically similar infiltration and erosion rates. Since the vegetation on these plots ranged from no above ground biomass and 0% cover to 1,000 to 3,000 kg/ha of forage with 40-70% cover; it must be concluded that instantaneous removal of vegetation on soils similar to those in this study does not immediately



1/ The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P \leq .05$). The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$).

Figure 5 . Mean infiltration rates measured on DIP plots sampled during June-July, 1971. 'A', 'B', and 'C' protected from grazing for five years, three years, and eight months respectively. The comparison of grazing exclosures (with clipping subtreatments pooled) versus the grazed condition is illustrated by 'D'. Infiltration rates are not plotted at the 3-, 8-, and 13-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.

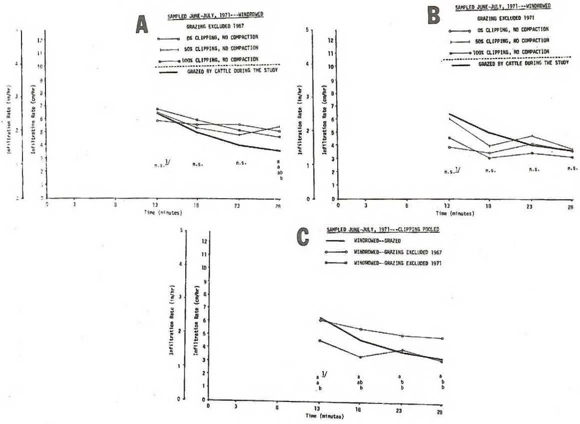


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Figure 6 . Mean infiltration rates measured on windrowed plots sampled during June-July, 1971. 'A', and 'B' respecitvely protected from grazing for five years and eight months. The comparison of grazing exclosures (with clipping subtreatments pooled) versus the grazed condition is illustrated by 'C '. Infiltration rates are not plotted at the 3- and 8-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.

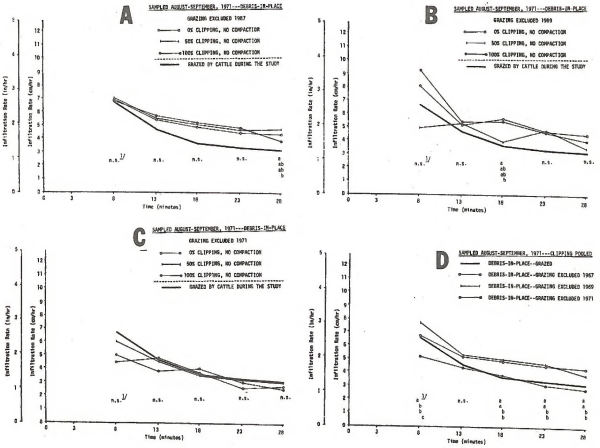

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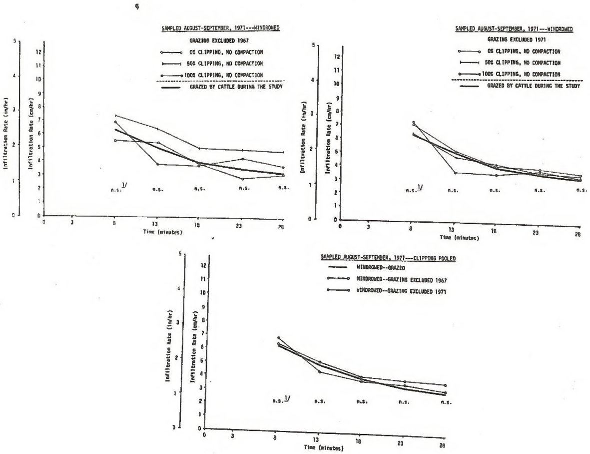
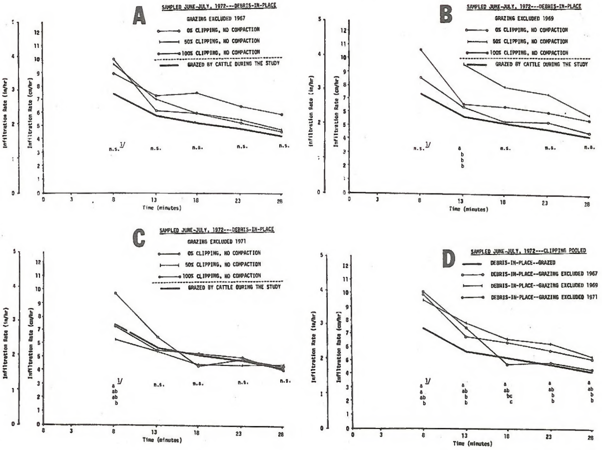
Figure 7 . Mean infiltration rates measured on DIP plots sampled during August-September, 1971. 'A', 'B', and 'C' protected from grazing for five years, three years, and eight months respectively. The comparison of grazing exclosures (with clipping subtreatments pooled) versus the grazed condition is illustrated by 'D'. Infiltration rates are not plotted at the 3-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



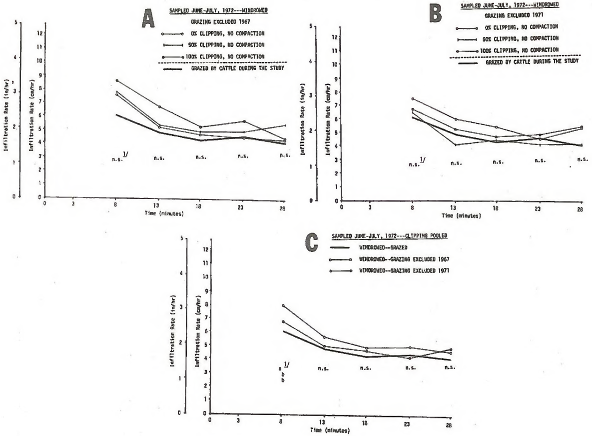
1/ The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P \leq .05$).

Figure 8 . Mean infiltration rates measured on windrowed plots sampled during August-September, 1971. 'A' and 'B', respectively, protected from grazing for five years and eight months. The comparison of grazing exclosures (with clipping subtreatments pooled) versus the grazed condition is illustrated by 'C'. Infiltration rates are not plotted at the 3-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



1/ The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P \leq .05$). The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$).

Figure 9 . Mean infiltration rates measured on DIP plots sampled during June-July, 1972. 'A', 'B', and 'C' protected from grazing for five years, three years, and eight months respectively. The comparison of grazing exclosures (with clipping subtreatments pooled) versus the grazed condition is illustrated by 'D'. Infiltration rates are not plotted at the 3-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



1/ The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P \leq .05$). The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$).

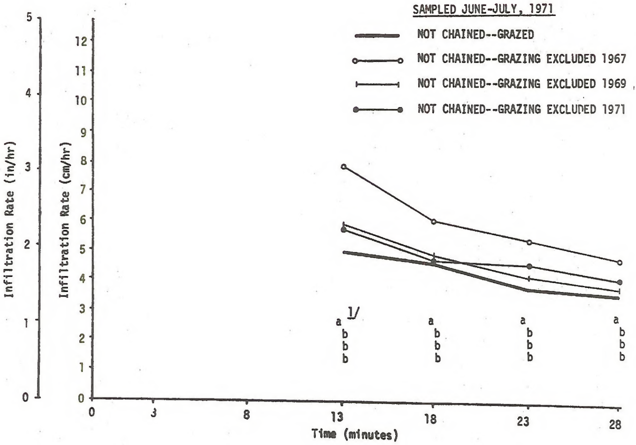
Figure 10. Mean infiltration rates measured on windrowed plots sampled during June-July, 1972. 'A', and 'B' respectively protected from grazing for five years and eight months. The comparison of grazing exclosures (with clipping subtreatments pooled) versus the grazed condition is illustrated by 'C'. Infiltration rates are not plotted at the 3-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.

influence microhydrologic systems within the pinyon-juniper vegetation type. The influence of complete or partial removal of forage for longer periods of time is unknown.

This conclusion is easier to understand when we consider that most studies that have found vegetative production or cover an important factor controlling infiltration or erosion rates were conducted in areas where the vegetative cover could reach 90 to 100%. In the pinyon-juniper woodland, achieving this degree of cover is impossible -- or at least impractical. Even on the best vegetated and unclipped plots, enough bare soil was exposed that channels of bare soil could span the entire plot length. These channels delivered the runoff water and its suspended sediment to the collection area regardless of the vegetation surrounding the channel.

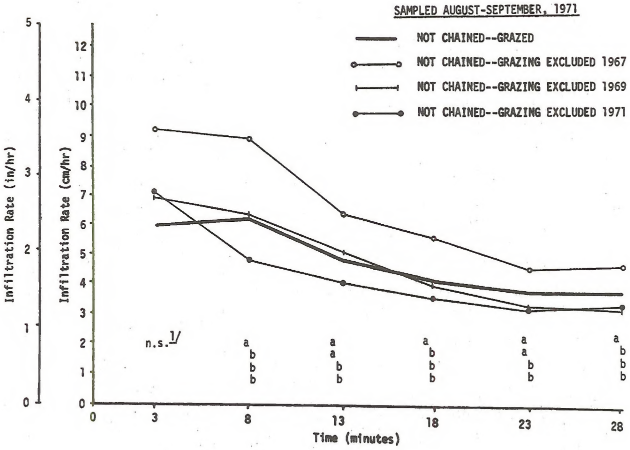
Although clipping did not affect infiltration or erosion rates, grazing by cattle did. Figures 5-D, 6-C, 7-D, 8-C, 9-D, and 10-C indicate the mean infiltration rates resulting when clipping subtreatments within each grazing exclosure were pooled. These were compared to infiltration rates on grazed plots. With few exceptions, grazed plots recorded the lowest infiltration rate (and highest sediment production rate). Generally, the difference in infiltration rates between grazed and protected plots increased with the period of time plots had been protected. In many instances, rest greater than 3 or 4 years (1969 exclosure) did not provide additional increases in infiltration rates.

Unchained plots, on which no herbaceous vegetation grew, indicated similar grazing effects (Figures 11 and 12): grazed plots had significantly lower infiltration rates than protected plots and the difference between grazed and protected conditions increased as the time of protection from grazing increased.



1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$).

Figure 11. Mean infiltration rates measured on unchained plots sampled during June-July, 1971. Infiltration rates are not plotted at the 3- and 8-minute intervals because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



1/ The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P \leq .05$). The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$).

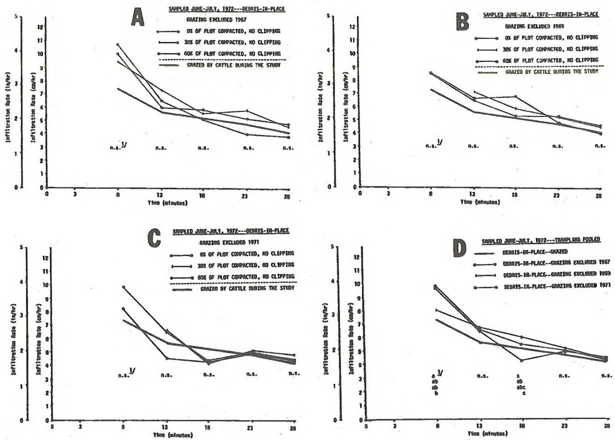
Figure 12. Mean infiltration rates measured on unchained plots sampled during August-September, 1971.

Because these unchained plots had no herbaceous vegetation growing on them; the low infiltration rates measured on grazed plots in this condition indicated the need to study some influence of livestock grazing other than forage removal and soil compaction by livestock trampling was selected as a factor needing evaluation.

First, to make a long story short, there were few significant differences in infiltration rates among compaction intensities (0, 30, 60%) on any of the chaining treatments, regardless of length of time protected from grazing (Figure 13-A,B,C; 14-A,B; 15-A,B,C; 16-A,B,C; 17-A,B; and 18-A,B,C). Significant differences that did exist between compaction subtreatments were not consistent; i.e., "0% compacted" may have been significantly higher or lower than "30% or 60% compacted" in one instance, while one of these latter conditions may have been significantly different from the other two in the next comparison. As a result of these findings, data from all compaction subtreatments within a grazing exclosure were pooled to determine the influence of protection from grazing (Figure 13-D, 14-C, 15-D, 16-D, 17-C, and 18-D). When grazing exclosures (with compaction subtreatments pooled) results are similar to those indicated from the clipping studies: grazing tends to decrease infiltration rates, but rest from grazing allows infiltration rates to recover. The amount of recovery is related to the period of time an area has been protected from grazing.

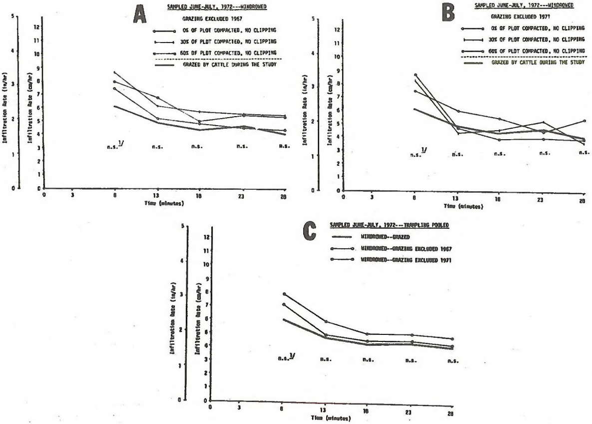
REPORT OF ADDITIONAL FINDINGS:

A complete report of all results obtained from the infiltration study of livestock grazing impacts on pinyon-juniper sites will be



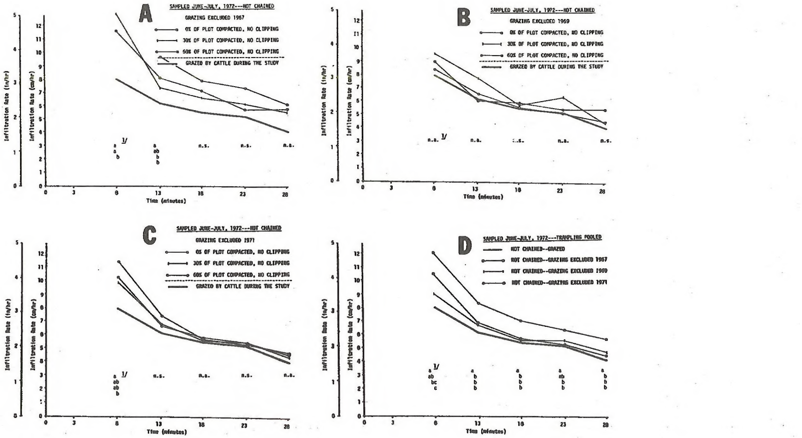
1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$). The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P > .05$).

Figure 13. Mean infiltration rates measured on DIP plots sampled during June-July, 1972. 'A', 'B', and 'C' protected from grazing for six years, four years, and one year-eight months, respectively. The comparison of grazing exclosures (with trampling subtreatments pooled) versus the grazed condition is illustrated by 'D'. Infiltration rates are not plotted at the 3-minute interval because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



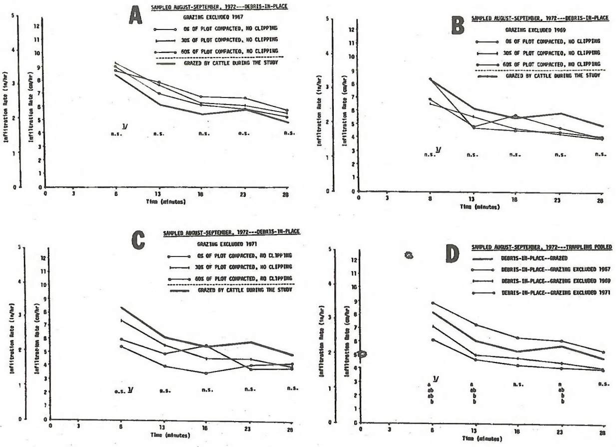
1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$). The sumbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P > .05$).

Figure 14. Mean infiltration rates measured on windrowed plots sampled during June-July, 1972. 'A', and 'B', respectively protected from grazing for six years and one year-eight months. The comparison of grazing exclosures (with trampling subtreatments pooled) versus the grazed condition is illustrated by 'C'. Infiltration rates are not plotted at the 3-minute interval because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



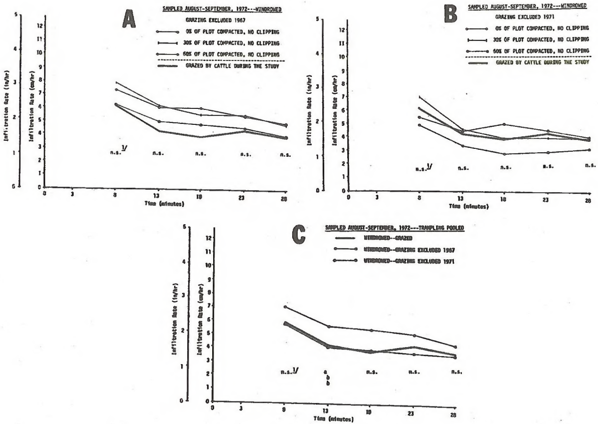
1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$). The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P > .05$).

Figure 15. Mean infiltration rates measured on not chained plots sampled during June-July, 1972. 'A', 'B', and 'C' protected from grazing for six years, four years, and one year - eight months, respectively. The comparison of grazing exclosures (with trampling subtreatments pooled) versus the grazed condition is illustrated by 'D'. Infiltration rates are not plotted at the 3-minute interval because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



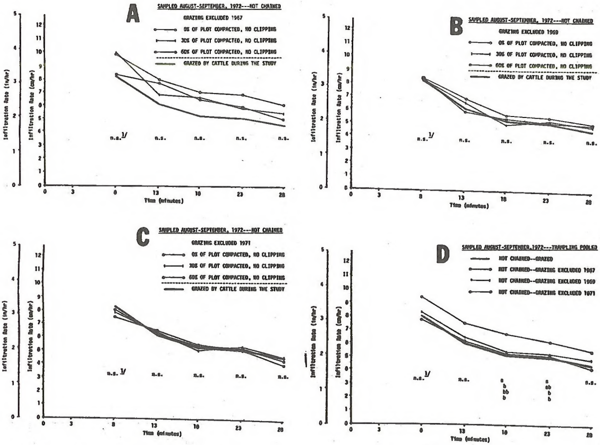
1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$). The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P > .05$).

Figure 16. Mean infiltration rates measured in DIP plots sampled during August-September, 1972. 'A', 'B', and 'C' protected from grazing for six years, four years, and one year-ten months, respectively. The comparison of grazing exclosures (with trampling subtreatments pooled) versus the grazed condition is illustration by 'D'. Infiltration rates are not plotted at the 3-minute interval because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$). The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P > .05$).

Figure 17. Mean infiltration rates measured on windrowed plots sampled during August-September, 1972. 'A', and 'B' respectively protected from grazing for six years and one year-ten months. The comparison of grazing exclosures (with trampling subtreatments pooled) versus the grazed condition is illustrated by 'C'. Infiltration rates are not plotted at the 3-minute interval because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.



1/ The order of the columns of letters corresponds to the order of the infiltration means plotted above the columns. Infiltration means not matched to the same letter are statistically different ($P \leq .05$). The symbol "n.s." denotes that the infiltration means plotted above the symbol are not statistically different ($P > .05$).

Figure 18. Mean infiltration rates measured on not chained plots sampled during August-September, 1972. 'A', 'B', and 'C' protected from grazing for six years, four years, and one year-ten months respectively. The comparison of grazing exclosures (with trampling subtreatments pooled) versus the grazed condition is illustrated by 'D'. Infiltration rates are not plotted at the 3-minute interval because simulated rainfall intensity was not great enough to induce runoff; thus infiltration capacity was not defined.

provided to the Bureau of Land Management in the form of a Ph.D. dissertation around July 1, 1973.

Vegetation Studies

Tables 7 and 8 give production data for 1971 and 1972.

Tables 9 and 10 give tree, shrub, and ground cover on windrow and debris-in-place runoff plots at the Blanding site during 1972. Cover is also presented in a form which would approximate very closely that obtained by the first contact method, thereby eliminating double counting on natural woodland plots.

Tables 11 and 12 provide cover data for runoff plots at the Milford site.

Table 7. Mean oven-dry yields (lbs./acre) for various treatments at each study site. Clipping data taken during September, 1971.

Site	Treatment		
	Control	Chain and Windrow	Chain with Debris-in-Place
Blanding	8 (shrub)	631 (grass) 7 (forb) 15 (shrub) 653	441 (grass) 30 (forb) 8 (shrub) 479
Milford - - - - - - - - - - - - - - - Rabbit Grazed			
	9 (grass) 36 (forb) 18 (shrub) 63	153 (grass) 81 (forb) 9 (shrub) 243	108 (grass) 99 (forb) 225 (shrub) 432
Milford - - - - - - - - - - - - - - - Rabbits Excluded			
	No rabbit-proff fencing in control area	495 (grass) 153 (forb) 18 (shrub) 666	234 (grass) 81 (forb) 270 (shrub) 585

Table 8. Mean oven-dry yields (lbs./acre) for various treatments at each study site. Clipping data taken during September, 1972.

Site	Treatment		
	Control	Chain and Windrow	Chain with Debris-in-Place
Blanding	Not clipped	380 (grass) 20 (shrub) 400	410 (grass) 7 (shrub) 417
Milford (Rabbits excluded)	Not clipped	680 (grass) 30 (forb) 10 (shrub) 720	350 (grass) 40 (forb) 150 (shrub) 540

Table 9. Tree, shrub, and ground cover on windrowed runoff plots at the Blanding study site, September, 1972.

Plot	Transect No. 1/	Percent Cover			
		Trees	Shrub	Ground 2/	
Windrow #1	19 ft.	0.00	0.00	BG	75.00
				Agcr	19.40
				L	5.60
	33 ft.	0.00	0.00	BG	64.38
				Agcr	31.17
				L	4.45
	55 ft.	0.00	0.00	BG	45.79
				Agcr	32.97
				L	21.24
	74 ft.	0.00	Artr 5.63	BG	56.99
				Agcr	19.24
				L	23.77
(Mean)	x̄	0.00	Artr 1.41	BG	60.54
				Agcr	25.69
				L	13.76
Windrow #2	19 ft.	0.00	0.00	BG	73.86
				Agcr	25.00
				L	1.14
	33 ft.	0.00	0.00	BG	75.05
				Agcr	18.57
				L	6.38
	55 ft.	0.00	0.00	BG	69.22
				Agcr	23.69
				L	7.09
	74 ft.	0.00	0.00	BG	50.56
				Agcr	24.63
				L	24.81
(Mean)	x̄	0.00	0.00	BG	67.17
				Agcr	22.91
				L	9.85

Table 9. Continued

Plot	Transect No. 1/	Percent Cover			
		Trees	Shrub	Ground 2/	
Windrow #3	19 ft.	0.00	Artr 1.32	BG Agcr L	70.24 16.95 12.81
	33 ft.	0.00	0.00	BG Agcr L	78.17 15.86 5.97
	55 ft.	0.00	0.00	BG Agcr L	51.64 19.34 29.02
	74 ft.	0.00	0.00	BG Agcr L	34.06 24.95 40.99
(Mean) $\bar{x}$		0.00	Artr 0.33	BG Agcr L	58.52 19.29 22.19
Windrow #4	19 ft.	0.00	0.00	BG Agcr L	67.30 22.81 9.89
	33 ft.	0.00	0.00	BG Agcr L	72.73 16.85 10.42
	55 ft.	0.00	0.00	BG Agcr L	43.53 17.82 38.65
	74 ft.	0.00	0.00	BG Agcr L	53.52 15.19 31.29
(Mean) $\bar{x}$		0.00	0.00	BG Agcr L	59.26 18.16 22.58

Table 9. Continued

Plot	Transect No. 1/	Percent Cover			
		Trees	Shrub	Ground 2/	
Windrow #5	19 ft.	0.00	0.00	BG Agcr L	28.57 38.80 32.63
	33 ft.	0.00	0.00	BG Agcr L	66.09 20.16 13.75
	55 ft.	0.00	0.00	BG Agcr L	82.75 12.60 4.65
	74 ft.	0.00	0.00	BG Agcr L	75.53 22.93 1.54
(Mean)	$\bar{x}$	0.00	0.00	BG Agcr L	63.23 23.63 13.14
Windrow Check #1	19 ft.	Pied 33.14 Juos 25.57	0.00	BG L	32.20 67.80
	33 ft.	Pied 18.08 Juos 21.47	Artr 9.98	BG L	31.13 56.87
	55 ft.	Pied 15.98 Juos 10.34	0.00	BG L	35.34 64.66
	74 ft.	Pied 35.02 Juos 26.22	0.00	BG L	10.86 89.14
(Mean)	$\bar{x}$	Pied 25.56 Juos 20.90	Artr 2.50	BG	27.38 69.62
19 ft.	Total 3/	Pied 33.14 Juos 25.57 BG 32.20 L 9.09			

Table 9. Continued

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	33 ft. Total 3/	Pied 18.08 Juos 21.47 Artr 9.98 BG 38.98 L 11.49		
	55 ft. Total 3/	Pied 15.98 Juos 10.34 BG 35.34 L 38.34		
	74 ft. Total 3/	Pied 35.02 Juos 26.22 BG 10.86 L 27.90		
	Total x̄	Pied 25.56 Juos 20.90 Artr 2.50 BG 29.34 L 21.70		
Windrow Check #2	19 ft.	Pied 8.93 Juos 34.13	0.00	BG 55.16 Opuntia spp. 1.98
	33 ft.	0.00	0.00	BG 88.09 L 11.91
	55 ft.	Juos 25.35	0.00	BG 48.69 L 51.31
	74 ft.	Juos 4.85	0.00	BG 70.91 29.09
	(Mean) x̄	Pied 2.23 Juos 16.08	0.00	BG 65.71 L 33.79 Opuntia spp. 0.50
	19 ft. Total 3/	Pied 8.93 Juos 34.13 BG 51.98 L 2.98 Opuntia spp 1.98		

Table 9. Continued

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground2/
	33 ft. Total3/	BG 88.09		
		L 11.91		
	55 ft. Total3/	Juos 25.35		
		BG 48.69		
		L 25.36		
	74 ft. Total3/	Juos 4.85		
		BG 70.91		
		24.24		
	Total $\bar{x}$	Pied 2.23		
		Juos 16.08		
		BG 64.92		
		L 16.27		
		Opuntia spp. .50		
Windrow Check #3	19 ft.	Pied 4.23 Juos 21.92	0.00	BG 64.23 L 35.77
	33 ft.	Pied 6.00	0.00	BG 73.50 L 26.50
	55 ft.	Juos 34.11	Ephedra spp. 3.87	BG 46.32 L 53.68
	74 ft.	Juos 13.73	0.00	BG 16.86 L 83.14
	Mean ($\bar{x}$)	Pied 2.56 Juos 17.44	Ephedra spp. 0.97	BG 50.23 L 49.77
	19 ft. Total3/	Pied 4.23		
		Juos 21.92		
		BG 64.24		
		L 9.61		
	33 ft. Total3/	Pied 6.00		
		BG 72.15		
		L 21.85		
	55 ft. Total3/	Juos 34.11		
		BG 33.14		
		L 28.88		

Table 9. Continued

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	74 ft. Total 3/	Juos 13.73 BG 16.27 L 70.00		
	Total $\bar{x}$	Pied 2.56 Juos 17.44 BG 46.45 L 33.55		
Windrow Check #4	19 ft.	Juos 29.33	0.00	BG 55.91 L 44.09
	33 ft.	Pied 10.04 Juos 12.36	Artr 5.60	BG 46.53 L 53.47
	55 ft.	Pied 13.76 Juos 29.34	0.00	BG 58.33 L 41.67
	74 ft.	Pied 3.87 Juos 22.63	Artr 15.12	BG 47.48 L 52.52
	(Mean) $\bar{x}$	Pied 6.92 Juos 22.63	Artr 5.18	BG 52.06 L 47.94
	19 ft. Total 3/	Juos 29.33 BG 55.91 L 14.76		
	33 ft. Total 3/	Pied 10.04 Juos 12.36 Artr 5.60 BG 45.95 L 26.05		
	55 ft. Total 3/	Pied 13.76 Juos 29.84 BG 48.65 L 5.23 Misc. 2.52		
	74 ft. Total 3/	Pied 3.87 Juos 18.99 Artr 15.12 BG 38.18 L 23.84		

Table 9. Continued

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	Total x̄	Pied 6.92 Juos 22.63 Artr 5.18 BG 47.17 L 17.47 Misc. .63		
Windrow Check #5	19 Ft.	Juos 30.28	0.00	BG 52.20 L 47.80
	33 ft.	Pied 18.89 15.46	0.00	BG 31.87 L 68.13
	55 ft.	Pied 3.03 Juos 10.22	0.00	BG 29.55 L 70.45
	74 ft.	Pied 20.49	0.00	BG 65.84 L 34.16
	(Mean) x̄	Pied 10.60 Juos 13.99	0.00	BG 56.08 L 43.92
	19 ft. Total 3/	Juos 30.28 BG 51.56 L 18.16		
	33 ft. Total 3/	Pied 18.89 Juos 15.46 BG 31.37 L 33.78		
	55 ft. Total 3/	Pied 3.03 Juos 10.22 BG 29.55 L 57.20		
	74 ft. Total 3/	Pied 20.49 BG 65.84 L 13.67		
	Total x̄	Pied 10.60 Juos 13.99 BG 44.70 L 30.71		

1/ Line transects across runoff plots at indicated distances measured from top of plot.

2/ Pied = *Pinus edulis*
Juos = *Juniperus osteosperma*
BG = Bare Ground
L = Litter
Artr = *Artemisia tridentata*

3/ This category represents a measure of ground cover as determined by the line intercept method but which would approximate closely ground cover obtained by the first contact method. This category eliminates any double counting, i.e., cover or bare ground under a shrub or tree canopy is not counted.

Table 10. Tree, shrub, and ground cover (percent) on debris-in-place runoff plots at the Blanding study site, September, 1972.

Plot	Transect No. [1/]	Percent Cover Trees	Shrub	Ground [2/]
Debris-in-Place #1	19 ft.	Juos 3.77	0.00	BG 62.07 Agcr 1.89 L 30.75 Orhy 3.21 Misc. 2.08
	33 ft.	0.00	0.00	BG 43.51 Agcr 22.90 L 33.59
	55 ft.	0.00	0.00	BG 42.88 Agcr 16.32 L 40.80
	74 ft.	Juos 5.51	Ephedra spp. 2.09	BG 17.49 Agcr 72.24 L 10.27
	(Mean) $\overline{x}$	Juos 2.32	Ephedra spp. 0.52	BG 41.49 Agcr 28.34 L 28.85 Orhy 0.80 Misc. 0.52
Debris-in-place #2	19 ft.	Juos 4.78	0.00	BG 54.68 Agcr 19.50 L 25.82
	33 ft.	0.00	Chrysothamnus spp. 1.16	BG 36.68 Agcr 50.39 L 12.93
	55 ft.	0.00	Misc. 4.62	BG 36.92 Agcr 18.08 L 45.00
	74 ft.	Juos 10.25	0.00	BG 43.33 Agcr 49.13 L 7.74
	(Mean) $\overline{x}$	Juos 3.76	Chrysothamnus spp. 0..29 Misc. 1.16	BG 42.90 Agcr 34.28 L 22.87

Table 10. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
Debris-in-Place #3	19 ft.	0.00	0.00	BG 38.05 Agcr 22.75 L 37.67 Orhy 1.53
	33 ft.	0.00	0.00	BG 10.69 Agcr 14.69 L 72.14 Saka 2.48
	55 ft.	0.00	0.00	BG 20.95 Agcr 19.81 L 59.24
	74 ft.	0.00	0.00	BG 31.88 Agcr 13.09 L 55.03
	(Mean) $\overline{x}$	0.00	0.00	BG 25.39 Agcr 17.59 L 56.02 Orhy 0.38 Saka 0.62
Debris-in-place #4	19 ft.	0.00	0.00	BG 37.52 Agcr 14.10 L 48.38
	33 ft.	0.00	0.00	BG 34.29 Agcr 38.89 L 26.82
	55 ft.	0.00	0.00	BG 68.44 Agcr 19.39 L 12.17
	74 ft.	0.00	0.00	BG 7.20 Agcr 8.90 L 80.68 Saka 3.22
	(Mean) $\overline{x}$	0.00	0.00	BG 36.86 Agcr 20.32 L 42.01 Saka 0.81

Table 10. Continued.

Plot	Transect No. [1]	Percent Cover		
		Trees	Shrub	Ground [2]
Debris-in-place #5	19 ft.	0.00	0.00	BG 51.14 Agcr 25.86 L 23.00
	33 ft.	0.00	0.00	BG 34.59 Agcr 17.01 L 48.40
	55 ft.	Juos 5.30	0.00	BG 14.77 Agcr 40.72 L 37.69 Misc. 3.79 Opuntia spp. 3.03
	74 ft.	0.00	0.00	BG 43.05 Agcr 24.95 L 29.71 Misc. 2.29
	(Mean) $\overline{x}$	Juos 1.33	0.00	BG 35.89 Agcr 27.14 L 37.70 Misc. 1.52 Opuntia spp. 0.76
Debris-in-Place Check #1	19 ft.	Jucs 13.18 Pied 45.93	0.00	BG 26.16 L 73.84
	33 ft.	Juos 53.00 Pied 18.57	0.00	BG 18.57 L 81.43
	55 ft.	Juos 42.45	0.00	BG 56.41 L 43.59
	74 ft.	Juos 12.88	0.00	BG 85.19 L 14.81
	(Mean) $\overline{x}$	Juos 30.33 Pied 16.13	0.00	BG 46.58 L 53.42
	19 ft. Total [3]	Juos 13.18 Pied 45.93 BG 26.16 L 14.73		

Table 10. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	33 ft. Total 3/			
		Juos 53.00 Pied 18.57 BG 18.57 L 9.86		
	55 ft. Total 3/			
		Juos 42.25 BG 46.85 L 10.90		
	74 ft. Total 3/			
		Juos 12.88 BG 86.16 L 0.96		
	Total $\overline{x}$	Juos 30.33 Pied 16.13 BG 44.44 L 9.10		
Debris-in-place Check #2	19 ft.	Juos 19.09 Pied 9.96	0.00	BG 75.55 L 24.45
	33 ft.	Juos 28.88 Pied 12.40	0.00	BG 47.87 L 52.13
	55 ft.	Juos 20.45 Pied 18.76	0.00	BG 47.91 L 52.09
	74 ft.	Juos 41.67 Pied 11.17	0.00	BG 23.30 L 76.70
	(Mean) $\overline{x}$	Juos 27.52 Pied 13.07	0.00	BG 48.66 L 51.34
	19 ft. Total 3/			
		Juos 19.09 Pied 9.96 BG 70.78 L 3.17		
	33 ft. Total 3/			
		Juos 28.88 Pied 12.40 BG 47.87 L 10.85		

Table 10. Continued.

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	55 ft. Total 3/			
		Juos 20.45 Pied 18.76 BG 47.91 L 12.88		
	74 ft. Total 3/			
		Juos 41.67 Pied 11.17 BG 23.30 L 23.86		
	Total $\bar{x}$	Juos 27.52 Pied 13.07 BG 47.46 L 11.95		
Debris-in-place Check #3	19 ft.	Juos 48.48	0.00	BG 50.00 L 50.00
	33 ft.	Juos 30.30 Pied 13.64	0.00	BG 65.53 L 34.47
	55 ft.	Juos 14.77	0.00	BG 51.14 L 48.86
	74 ft.	Juos 16.70	0.00	BG 74.28 L 25.72
	(Mean) $\bar{x}$	Juos 27.56 Pied 3.41	0.00	BG 60.24 L 39.76
	19 ft. Total 3/			
		Juos 48.48 BG 47.35 L 41.67		
	33 ft. Total 3/			
		Juos 30.30 Pied 13.64 BG 52.84 L 3.22		
	55 ft. Total 3/			
		Juos 14.77 BG 51.14 L 34.09		

Table 10. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	74 ft. Total 3/	Juos 16.70 BG 72.74 L 10.56		
	Total $\bar{x}$	Juos 27.56 Pied 3.41 BG 56.02 L 13.01		
Debris-in-place Check #4	19 ft.	Juos 82.77	0.00	BG 93.37 L 6.63
	33 ft.	Juos 35.42 Pied 13.44	0.00	BG 36.74 L 63.26
	55 ft.	Juos 51.11 Pied 22.73	0.00	BG 61.74 L 38.26
	74 ft.	Juos 24.84 Pied 8.70	0.00	BG 31.25 L 68.75
	(Mean) $\bar{x}$	Juos 48.54 Pied 11.22	0.00	BG 55.78 L 44.22
	19 ft. Total 3/	Juos 82.77 BG 9.28 L 7.95		
	33 ft. Total 3/	Juos 35.42 Pied 13.44 BG 35.80 L 15.34		
	55 ft. Total 3/	Juos 51.11 Pied 22.73 BG 61.74 L 10.42		
	74 ft. Total 3/	Juos 24.84 Pied 8.70 BG 33.95 L 32.51		

Table 10. Continued.

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	Total $\overline{x}$	Juos 48.54 Pied 11.22 BG 35.19 L 5.05		
Debris-in-place Check #5	19 ft.	Juos 20.45 Pied 22.35	0.00	BG 19.89 L 80.11
	33 ft.	Juos 45.27	0.00	BG 47.73 L 52.57
	55 ft.	Juos 17.17	0.00	BG 45.47 L 54.53
	74 ft.	Juos 42.18	0.00	BG 39.50 L 60.50
	(Mean) $\overline{x}$	Juos 31.27 Pied 5.59	0.00	BG 38.15 L 61.85
	19 ft. Total 3/	Juos 20.45 Pied 22,35 BG 14.77 L 42.43		
	33 ft. Total 3/	Juos 45.27 BG 37.31 L 17.42		
	55 ft. Total 3/	Juos 17.17 BG 45.47 L 37.36		
	74 ft. Total 3/	Juos 42.18 BG 41.79 L 16.03		

Table 10. Continued.

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	Total $\overline{x}$	Juos 31.27 Pied 5.59 BG 34.84 L 28.30		

1/ Line transects across runoff plots at indicated distances measured from top of plot.

2/

Juos = *Juniperus osteosperma*
Pied = *Pinus edulis*
Orhy = *Oryzopsis hymenoides*
Agcr = *Agropyron cristatum*
BG = Bare Ground
L = Litter

3/ This category represents a measure of ground cover as determined by the line intercept method but which would approximate closely ground cover obtained by the first contact method. This category eliminates any double counting, i.e., cover or bare ground under a shrub or tree canopy is not counted.

Table 11. Tree, shrub, and ground cover (percent) on windrowed runoff plots at the Milford study stie, September, 1972.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/	
Windrow #1	19 ft.	0.00	0.00	BG	44.81
				Agcr	29.23
				L	7.31
				EP	17.69
				Penstemon spp.	0.96
	33 ft.	0.00	Arno 5.89	BG	36.50
				Agcr	24.70
				L	20.00
				EP	9.30
				Rock	5.10
				Penstemon spp.	2.10
				Sphaeralcea spp.	2.30
	55 ft.	0.00	0.00	BG	16.80
				Agcr	27.60
				L	23.40
				EP	32.20
	74 ft.	0.00	0.00	BG	50.70
				Agcr	25.30
				L	14.00
				EP	2.70
				Rock	6.00
				Sphaeralcea spp.	1.30
	(Mean) $\bar{x}$	0.00	Arno 1.47	BG	37.20
				Agcr	26.71
				L	16.18
				EP	15.48
				Penstemon spp.	0.77
				Rock	2.78
				Sphaeralcea spp.	0.91
Windrow #2	19 ft.	0.00	0.00	BG	43.60
				Agcr	29.10
				L	12.80
				EP	13.10
				Lupine spp.	1.00
				Misc.	0.40
	33 ft.	0.00	0.00	BG	33.06
				Agcr	27.89
				L	21.69
				EP	14.67
				Sphaeralcea spp.	2.69

Table 11. Continued

Plot	Transect No.[1]	Percent Cover Trees	Shrub	Ground [2]
Windrow #2	55 ft.	0.00	0.00	BG 41.18
				Agcr 17.65
				L 29.41
				EP 11.76
	74 ft.	0.00	0.00	BG 4.79
				Agcr 21.92
				L 20.32
				EP 52.97
(Mean) $\bar{x}$		0.00	0.00	BG 30.66
				Agcr 24.14
				L 21.06
				EP 23.12
				Sphaeralcea spp. 0.67
				Lupine spp. 0.25
				Misc. 0.10
Windrow #3	19 ft.	0.00	0.00	BG 61.61
				Agcr 19.40
				L 11.32
				EP 4.99
				Penstemon spp. 1.34
				Rock 1.34
	33 ft.	0.00	0.00	BG 63.98
				Agcr 14.76
				L 19.73
				EP 1.53
	55 ft.	0.00	0.00	BG 56.60
				Agcr 20.27
				L 13.19
				EP 5.16
				Penstemon spp. 0.76
				Rock 4.02
	74 ft.	0.00	0.00	BG 61.45
				Agcr 25.95
				L 6.68
				Penstemon spp. 5.92
	(Mean) $\bar{x}$	0.00	0.00	BG 60.91
				Agcr 20.10
				L 12.73
				EP 2.92
				Penstemon spp. 2.01
				Rock 1.33

Table 11. Continued

Plot	Transect No. 1/	Trees	Shrub	Ground 2/
Windrow #4	19 ft.	0.00	0.00	BG 42.96
				Agcr 23.80
				L 23.22
				Penstemon spp. 1.34
				Lupine spp. 8.68
	33 ft.	0.00	0.00	BG 47.78
				Agcr 18.69
				L 30.64
				Penstemon spp. 2.89
	55 ft.	0.00	Arno 1.35	BG 60.19
				Agcr 24.62
				L 11.35
				Penstemon spp. 0.38
				Lupine spp. 3.46
	74 ft.	0100	Arno 1.34	BG 56.03
				Agcr 17.57
				L 21.22
				Lupine spp. 5.18
	(Mean) $\bar{x}$	0.00	Arno 0.67	BG 51.75
				Agcr 21.17
				L 21.61
				Penstemon spp. 1.15
				Lupine spp. 4.32
Windrow #5	19 ft.	0.00	0.00	BG 57.14
				Agcr 27.22
				L 10.23
				Lupine spp. 4.44
				Rock 0.97
	33 ft.	0.00	0.00	BG 59.12
				Agcr 31.48
				L 9.40
	55 ft.	0.00	0.00	BG 47.79
				Agcr 32.44
				L 19.77
	74 ft.	0.00	0.00	BG 51.45
				Agcr 32.12
				L 16.43
	(Mean) $\bar{x}$	0.00	0.00	BG 53.88
				Agcr 30.82
				L 13.72
				Lupine spp. 1.21
				Rock 0.37

Table 11. Continued

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
Windrow Check #1	19 ft.	Juos 45.02	0.00	BG 37.93 L 49.43 Moss 12.64
	33 ft.	Juos 11.83 Pied 18.32	0.00	BG 46.95 L 53.05
	55 ft.	Juos 20.45	0.00	BG 18.77 L 81.23
	74 ft.	0.00	Gusa 2.46	BG 83.90 L 14.96 Orhy 1.14
	(Mean) $\overline{x}$	Juos 19.32 Pied 4.58	Gusa 0.62	BG 46.90 L 49.67 Moss 3.14 Orhy 0.29
	19 ft. Total 3/	Juos 45.02 BG 37.93 L 17.05		
	33 ft. Total 3/	Juos 11.83 Pied 18.32 BG 46.95 L 22.90		
	55 ft. Total 3/	Juos 20.45 BG 14.85 L 64.70		
	74 ft. Total 3/	BG 83.90 L 12.69 Orhy 0.95 Gusa 2.46		
	Total $\overline{x}$	Juos 19.32 Pied 4.58 BG 45.91 L 29.34 Orhy 0.24 Gusa 0.61		

Table 11. Continued

Plot	Transect No. 1/	Percent cover: Trees	Percent cover: Shrubs	Percent cover: Ground 2/
Windrow Check #2	19 ft.	Juos 7.21	0.00	BG 16.57
		Pied 37.04		L 81.48
				Penstemon spp. 0.78
				Orhy 0.39
				Misc. 0.78
	33 ft.	Juos 16.60	0.00	BG 18.18
		Pied 8.10		L 76.68
				Rock 5.14
	55 ft.	Pied 16.10	Putr 3.58	BG 46.92
				L 53.08
	74 ft.	Juos 41.57	Arno 0.20	BG 20.59
				L 73.14
				EP 6.27
	(Mean) $\bar{x}$	Juos 16.35	Putr 0.90	BG 25.57
		Pied 15.31	Arno 0.05	L 71.10
				Penstemon spp. 0.20
				Orhy 0.10
				Rock 1.29
				Misc. 0.20
				EP 1.54
	19 ft. Total 3/			
		Juos 7.21		
		Pied 37.04		
		BG 16.57		
		L 38.01		
		Penstemon spp. 0.78		
		Orhy 0.39		
	33 ft. Total 3/			
		Juos 16.60		
		Pied 8.10		
		BG 15.02		
		L 55.14		
		Rock 5.14		
	55 ft. Total 3/			
		Pied 16.10		
		BG 44.14		
		L 36.18		
		Putr 3.58		

Table 11. Continued.

Plot	Transect No. [1]	Percent Cover		
		Trees	Shrubs	Ground[2]
	74 ft. Total [3]	Juos 41.57 BG 15.49 L 31.18 Arno 0.20 EP 11.56		
	Total $\overline{x}$	Juos 16.35 Pied 15.31 BG 22.80 L 40.13 Penstemon spp. 0.19 Orhy 0.10 Putr 0.89 Arno 0.05 Rock 1.29 EP 2.89		
Windrow Check #3	19 ft.	Juos 60.94	Arno 0.78	BG 39.06 L 60.94
	33 ft.	Pied 39.65	0.00	BG 35.59 L 62.67 Opuntia spp. 1.74
	55 ft.	0.00	0.00	BG 82.95 L 17.05
	74 ft.	Pied 49.90	0.00	BG 55.15 L 40.58 Opuntia spp. 2.52 Misc. 1.75
	(Mean) $\overline{x}$	Juos 15.24 Pied 22.39	Arno 0.19	BG 53.19 L 45.31 Opuntia spp. 1.06 Misc. 0.44
	19 ft. Total[3]	Juos 60.94 BG 13.48 L 25.58		

Table 11. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	33 ft. Total 3/	Pied 39.65 BG 35.59 L 23.02 Opuntia spp. 1.74		
	55 ft. Total 3/	BG 82.95 L 17.05		
	74 ft. Total 3/	Pied 49.90 BG 28.93 L 16.89 Opuntia spp. 2.52 Misc. 1.76		
	Total $\overline{x}$	Juos 15.24 Pied 22.39 BG 40.24 L 20.63 Opuntia spp. 1.06 Misc. 0.44		
Windrow Check #4	19 ft.	Juos 18.22 Pied 4.26	Artr 2.91	BG 34.11 L 37.60 EP 28.29
	33 ft.	Juos 23.51 Pied 7.32	Artr 1.93 Arno 1.73	BG 45.09 L 53.76 Misc. 1.15
	55 ft.	0.00	Arno 8.12	BG 70.79 L 29.21
	74 ft.	Juos 21.88 Pied 46.29	Artr 4.30 Arno 4.69	BG 11.72 L 68.55 EP 19.73
	(Mean) $\overline{x}$	Juos 15.90 Pied 14.47	Artr 2.29 Arno 3.64	BG 40.43 L 47.28 EP 12.01 Misc. 0.28

Table 11. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Percent Cover Shrub	Percent Cover Ground 2/
	19 ft. Total 3/	Juos 18.22 Pied 4.26 BG 29.85 L 16.47 EP 28.29 Artr 2.91		
	33 ft. Total 3/	Juos 23.51 Pied 7.32 BG 39.69 L 24.66 Artr 1.93 Arno 1.73 Misc. 1.16		
	55 ft. Total 3/	BG 70.41 Arno 8.12 L 21.47		
	74 ft. Total 3/	Juos 21.88 Pied 46.28 BG 8.40 L 6.05 EP 12.70 Arno 4.69		
	Total $\overline{x}$	Juos 15.90 Pied 14.47 BG 37.09 L 17.16 EP 10.25 Artr 1.21 Arno 3.63 Misc. 0.29		
Windrow Check #5	19 ft.	Pied 34.29	0.00	BG 45.71 L 54.29
	33 ft.	Pied 36.59 Juos 10.92	Arno 0.77	BG 43.10 L 56.90

Table 11. Continued.

Plot	Transect No. [1]	Percent Cover Trees	Shrub	Ground [2]
	55 ft.	Juos 6.08	Arno 3.04	BG 78.71 L 20.91 Penstemon spp. 0.38
	74 ft.	Juos 26.05 Pied 0.76	Arno 4.75	BG 41.06 L 55.13 EP 3.81
	(Mean) $\overline{x}$	Juos 10.76 Pied 17.91	Arno 2.14	BG 52.15 L 46.80 Penstemon spp. 0.95 EP 0.95
	19 ft. Total [3]	Pied 34.29 BG 45.71 L 20.00		
	33 ft. Total [3]	Pied 36.59 Juos 10.92 BG 41.76 L 9.96 Arno 0.77		
	55 ft. Total [3]	Juos 6.08 BG 73.76 L 16.74 Penstemon spp. 0.38 Arno 3.04		
	74 ft. Total [3]	Juos 26.05 Pied 0.76 BG 36.12 L 29.28 EP 3.04 Arno 4.75		

Table 11. Continued.

Plot	Transect No. 1/	Percent Cover		
		Trees	Shrub	Ground 2/
	Total $\overline{x}$	Juos 10.76		
		Pied 17.91		
		BG 49.34		
		L 19.00		
		EP 0.76		
		Anro 2.14		
		Penstemon spp. 0.09		

1/ Line transects across runoff plots at indicated distances measured from to of plot.

2/
Juos = Juniperus osteosperma
Pied = Pinus edulis
Arno = Artemisia nova
Artr = Artemisia tridentata
BG = Bare Ground
L = Litter
Orhy = Oryzopsis hymenoides
Agcr = Agropyron cristatum
Gusa = Gutierrezia sarothrae
Putr = Purshia tridentata

3/ This category represents a measure of ground cover as determined by the line intercept method but which would approximate closely ground cover obtained by the first contact method. This category eliminates any double counting, i.e., cover or bare ground under a shrub or tree canopy is not counted.

Table 12. Tree, shrub, and ground cover (percent) on debris-in-place runoff plots at the Milford study site, September, 1972.

Plot	Transect No. [1]	Percent Cover: Trees	Percent Cover: Shrub	Percent Cover: Ground [2]
Debris-in-place #1	19 ft.	0.00	Artr 14.00	BG 2.00
			Gusa 2.00	Agcr 8.00
				L 28.00
				EP 54.70
				Sphaeralcea spp. 4.00
				Misc. 3.30
	33 ft.	0.00	Artr 5.42	BG 9.90
			Arno 0.74	Agcr 11.40
			Gusa 9.53	L 19.07
				EP 56.26
				Sphaeralcea spp. 1.50
				Phlox spp. 1.30
				Penstemon spp. 0.19
				Misc. 0.38
	55 ft.	0.00	Artr 9.96	BG 2.76
			Gusa 2.58	Agcr 11.07
				L 33.77
				EP 50.56
				Sphaeralcea spp. 1.47
				Phlox spp. 0.37
	74 ft.	Juos 8.74	Artr 3.46	BG 7.83
			Gusa 0.36	Agcr 10.38
				L 55.74
				EP 21.31
				Sphaeralcea spp. 2.19
				Orhy 1.09
				Phlox spp. 0.36
				Misc. 1.10
	(Mean) $\bar{x}$	Juos 2.18	Artr 8.21	BG 5.74
			Arno 0.18	Agcr 10.21
			Gusa 3.61	L 34.14
				EP 45.70
				Sphaeralcea spp. 2.29
				Phlox spp. 0.50
				Orhy 0.27
				Penstemon spp. 0.04
				Misc. 1.11
Debris-in-place #2	19 ft.	0.00	Arno 8.03	BG 15.37
				L 54.31
				Phlox spp. 1.43
				EP 28.89

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	33 ft.	0.00	Arno 2.39 Gusa 8.54	BG 11.87 L 25.21 EP 53.75 Agcr 3.75 Orhy 3.54 Sphaeralcea spp. 1.25 Rock 0.63
	55 ft.	0.00	Gusa 11.70	BG 14.89 L 38.51 EP 31.06 Agcr 7.66 Phlox spp. 5.11 Eriogonium spp. 1.28 Penstemon spp. 1.49
	74 ft.	0.00	Arno 8.99	BG 7.66 L 37.20 EP 41.79 Agcr 12.91 Sphaeralcea spp. 0.44
	(Mean) $\overline{x}$	0.00	Arno 7.32 Gusa 8.43	BG 12.44 L 38.80 EP 38.87 Agcr 6.08 Sphaeralcea spp. 0.43 Phlox spp. 1.64 Eriogonium spp. 0.33 Orhy 0.88 Penstemon spp. 0.38 Rock 0.15
Debris-in-place #3	19 ft.	0.00	Arno 3.13 Gusa 2.21	BG 13.64 L 67.77 EP 3.68 Agcr 13.08 Sphaeralcea spp. 0.18 Phlox spp. 0.55 Misc. 1.10
	33 ft.	0.00	Arno 6.06 Gusa 5.88	BG 6.41 L 61.50 EP 8.73 Agcr 20.86 Penstemon spp. 2.50

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	55 ft.	0.00	Arno 5.12 Gusa 4.48	BG 18.94 L 42.35 EP 12.56 Agcr 21.17 Sphaeralcea spp. 1.38 Phlox spp. 1.20 Orhy 2.40
	74 ft.	Juos 4.11	Arno 0.98 Gusa 4.28	BG 5.10 L 47.54 EP 33.55 Agcr 12.66 Sphaeralcea spp. 0.49 Penstemon spp. 0.66
	(Mean) $\overline{x}$	Juos 1.03	Arno 3.82 Gusa 4.21	BG 11.02 L 54.78 EP 14.63 Agcr 16.94 Sphaeralcea spp. 0.52 Phlox spp. 0.44 Orhy 0.60 Penstemon spp. 0.79 Misc. 0.28
Debris-in-place #4	19 ft.	0.00	Gusa 13.90	BG 16.38 L 58.67 Agcr 9.71 EP 14.10 Sphaeralcea spp. 1.14
	33 ft.	0.00	Arno 7.49	BG 6.93 L 36.89 Agcr 14.04 EP 36.89 Spaheralcea spp. 3.94 Phlox spp. 1.31
	55 ft.	0.00	Arno 1.65	BG 5.71 L 22.47 Agcr 11.23 EP 58.01 Sphaeralcea spp. 2.58

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Gound 2/
	74 ft.	0.00	Arno 2.36	BG 2.19 L 5.63 EP 71.40 Agcr 14.39 Sphaeralcea spp. 4.19 Phlox spp. 0.55 Lupine spp. 0.55 Misc. 1.10
	(Mean) $\overline{x}$	0.00	Arno 2.87 Gusa 5.02	BG 7.80 L 30.93 EP 45.11 Agcr 12.34 Sphaeralcea spp. 2.96 Phlox spp. 0.46 Lupine spp. 0.14 Misc. 0.26
Debris-in-place #5	19 ft.	Pied 8.84	Arno 3.84 Artr 2.50 Gusa 4.23	BG 5.96 L 51.54 EP 31.73 Agcr 9.81 Phlox spp. 0.53 Misc. 0.38
	33 ft.	Pied 3.47	Arno 18.18 Gusa 3.10	BG 3.10 L 33.66 EP 51.64 Agcr 9.28 Lupine spp. 1.35 Rock 0.39 Misc. 0.58
	55 ft.	Pied 2.51	Arno 14.14 Gusa 3.88	BG 10.47 L 48.64 EP 33.33 Agcr 3.88 Sphaeralcea spp. 0.58 Orhy 1.16 Misc. 1.94

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	74 ft.	Pied 0.76	Arno 2.49	BG 13.63
			Gusa 12.29	L 11.51
				EP 62.20
				Agcr 9.02
				Phlox spp. 0.38
				Misc. 2.69
				Saka 0.19
				Rock 0.38
	(Mean) $\overline{x}$	Pied 3.75	Arno 9.45	BG 8.28
			Gusa 5.87	L 36.34
				EP 44.75
				Agcr 8.25
				Sphaeralcea spp. 0.14
				Phlox spp. 0.24
				Orhy 0.29
				Rock 0.14
				Saka 0.05
				Lupine spp. 0.34
				Misc. 1.18
Debris-in-place Check #1	19 ft.	Juos 9.62	Artr 2.50	BG 75.19
			Arno 6.92	L 24.81
	33 ft.	Juos 33.33	Artr 3.41	BG 19.32
			Arno 1.70	L 66.48
				EP 12.50
				Orhy 1.70
	55 ft.	Juos 32.40	Arno 14.23	BG 24.53
				L 64.61
				EP 9.55
				Phlox spp. 0.56
				Orhy 0.75
	74 ft.	0.00	Arno 18.11	BG 50.46
				L 43.99
				EP 3.52
				Penstemon spp. 1.11
				Misc. 0.92
	(Mean) $\overline{x}$	Juos 18.83	Artr 1.47	BG 42.37
			Arno 8.08	L 49.97
				EP 6.39
				Phlox spp. 0.14
				Orhy 0.63
				Penstemon spp. 0.27
				Misc. 0.23

Table 12. Continued.

Plot	Transect No. [1]	Percent Cover		
		Trees	Shrub	Ground [2]
	19 ft. Total [3]			
		Juos 9.62		
		BG 68.27		
		L 12.69		
		Artr 2.50		
		Arno 6.92		
	33 ft. Total [3]			
		Juos 33.33		
		BG 18.18		
		L 29.17		
		EP 12.50		
		Orhy 1.70		
		Artr 3.42		
		Arno 1.70		
	55 ft. Total [3]			
		Juos 32.40		
		BG 24.16		
		L 19.29		
		EP 9.55		
		Phlox spp. 0.37		
		Arno 14.23		
	74 ft. Total [3]			
		BG 45.66		
		L 31.79		
		EP 3.52		
		Arno 18.11		
		Misc. 0.92		
	Total $\overline{x}$	Juos 18.83		
		BG 39.07		
		L 23.24		
		EP 6.39		
		Artr 1.48		
		Arno 10.24		
		Orhy 0.42		
		Phlox spp. 0.09		
		Misc. 0.24		
Debris-in-place Check #1	19 ft.	Juos 23.32	Artr 7.06	BG 3.45
			Arno 11.67	L 63.67
				EP 32.89

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	33 ft.	Juos 14.17 Pied 24.71	Artr 2.29 Arno 9.19	BG 7.66 L 63.22 EP 27.59 Phlox spp. 0.57 Orhy 0.96
	55 ft.	Juos 21.11	Artr 7.10 Arno 5.95	BG 0.96 L 59.12 EP 38.77 Misc. 1.15
	74 ft.	Pied 43.93	Artr 10.02 Arno 5.79	BG 5.01 L 78.23 EP 15.80 Orhy 0.96
	(Mean) $\overline{x}$	Pied 17.16 Juos 14.66	Artr 6.61 Arno 8.15	BG 4.28 L 66.06 EP 28.76 Phlox spp. 0.14 Orhy 0.48 Misc. 0.28
	19 ft. Total 3/	Juos 23.32 BG 3.45 L 21.40 EP 33.10 Arno 11.67 Artr 7.06		
	33 ft. Total 3/	Juos 14.17 Pied 24.71 BG 3.44 L 17.56 EP 27.11 Arno 9.19 Artr 2.29 Orhy 0.96 Phlox spp. 0.57		
	55 ft. Total 3/	Juos 21.11 BG 0.96 L 16.89 EP 46.84 Artr 7.10 Arno 5.95 Misc. 1.15		

Table 21. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	74 ft. Total 3/	Pied 43.93 BG 1.35 L 22.54 EP 15.41 Arno 5.79 Artr 10.02 Orhy 0.96		
	Total $\overline{x}$	Juos 14.66 Pied 17.16 BG 2.30 L 19.60 EP 30.62 Arno 8.15 Artr 6.62 Orhy 0.48 Phlox spp. 0.14 Misc. 0.27		
Debris-in-place Check #3	19 ft.	0.00	Arno 15.82	BG 37.30 L 17.77 EP 44.15 Orhy 0.78
	33 ft.	Pied 13.14	Artr 6.27 Arno 16.47	BG 21.18 L 61.37 EP 16.47 Misc. 0.98
	55 ft.	Juos 29.08 Pied 22.98	Arno 3.73	BG 7.08 L 58.15 EP 32.22 Opuntia spp. 2.55
	74 ft.	Juos 29.78	0.00	BG 24.06 L 42.41 EP 33.53
	(Mean) $\overline{x}$	Juos 14.71 Pied 9.03	Artr 1.56 Arno 9.00	BG 22.40 L 44.92 EP 31.60 Orhy 0.19 Opuntia spp. 0.64 Misc. 0.25

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover: Tree	Percent Cover: Shrub	Percent Cover: Ground 2/
	19 ft. Total 3/	BG 33.98 L 7.23 EP 42.19 Arno 15.82 Orhy 0.78		
	33 ft. Total 3/	Pied 13.14 BG 20.78 EP 26.67 L 14.51 Gusa 1.18 Artr 6.27 Arno 16.47 Misc. 0.98		
	55 ft. Total 3/	Juos 29.08 Pied 22.98 BG 7.47 L 13.16 EP 23.58 Arno 3.73		
	74 ft. Total 3/	Juos 29.78 BG 21.70 L 14.99 EP 33.53		
	Total $\overline{x}$	Juos 14.71 Pied 9.03 BG 20.98 L 12.47 EP 31.49 Arno 9.00 Artr 1.56 Orhy 0.20 Misc. 0.56		
Debris-in-place Check #4	19 ft.	Juos 4.10	Arno 1.17	BG 4.30 L 41.00 EP 54.70
	33 ft.	0.00	0.00	BG 1.75 L 2.72 EP 95.53

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	55 ft.	Juos 29.08 Pied 24.36	Arno 4.32	BG 3.34 L 96.66
	74 ft.	Juos 15.13 Pied 16.90	0.00	BG 4.52 L 42.44 EP 53.04
	(Mean) $\bar{x}$	Juos 12.07 Pied 10.31	Arno 1.37	BG 3.47 L 45.70 EP 50.83
	19 ft. Total 3/	Juos 4.10 BG 5.47 L 34.57 EP 54.69 Arno 1.17		
	33 ft. Total 3/	BG 1.75 L 2.72 EP 95.53		
	55 ft. Total 3/	Juos 29.08 Pied 24.36 BG 6.68 L 35.56 Arno 4.32		
	74 ft. Total 3/	Juos 15.13 Pied 16.90 BG 4.52 L 15.91 EP 47.54		
	Total $\bar{x}$	Juos 12.07 Pied 10.31 BG 4.60 L 22.19 EP 49.46 Arno 1.37		

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
Debris-in-place Check #5	19 ft.	Juos 18.99	Artr 5.81 Arno 13.95	BG 8.91 L 62.99 EP 28.10
	33 ft.	Juos 24.03	Arno 4.07	BG 16.47 L 58.72 EP 24.81
	55 ft.	Juos 12.60 Pied 63.40	Arno 1.90	BG 3.70 L 76.30 EP 18.70 Orhy 1.30
	74 ft.	Pied 28.80	Arno 1.00	BG 9.50 L 53.90 EP 36.60
	(Mean) $\overline{x}$	Juos 13.91 Pied 23.05	Artr 1.45 Arno 5.23	BG 9.65 L 62.98 EP 27.05 Orhy 0.32
	19 ft. Total 3/	Juos 18.99 BG 3.10 L 26.75 EP 31.40 Artr 5.81 Arno 13.95		
	33 ft. Total 3/	Juos 24.03 BG 8.53 L 38.95 EP 24.42 Arno 4.07		
	55 ft. Total 3/	Juos 12.60 Pied 63.40 BG 4.70 L 1.40 EP 16.00 Arno 1.90		

Table 12. Continued.

Plot	Transect No. 1/	Percent Cover Trees	Shrub	Ground 2/
	74 ft. Total 3/			
		Pied 28.80		
		BG 7.60		
		L 27.00		
		EP 35.60		
		Arno 1.00		
	Total $\bar{x}$	Juos 13.91		
		Pied 23.05		
		BG 5.98		
		L 23.52		
		EP 26.86		
		Artr 1.45		
		Arno 5.23		

1/ Line transects across runoff plots at indicated distances measured from top of plot.

2/

Juos = *Juniperus osteosperma*
Pied = *Pinus edulis*
Arno = *Artemisia nova*
Artr = *Artemisia tridentata*
Orhy = *Oryzopsis hymenoides*
Agcr = *Agropyron cristatum*
BG = Bare Ground
L = Litter
EP = Erosion Pavement

3/ This category represents a measure of ground cover as determined by the line intercept method but which would approximate closely ground cover obtained by the first contact method. This category eliminates any double counting, i.e., cover or bare ground under a shrub or tree canopy is not counted.

Appendix 1

Manuscripts

1. "Runoff Sediment Yields from Runoff Plots on Chained Pinyon-Juniper Sites in Utah".
2. "Soil Moisture Patterns on Two Chained Pinyon-Juniper Sites in Utah".
3. "Sap Velocities in Pinyon and Juniper Trees and Their Relationship to Measured Environmental Factors".
4. "Improved Prediction of Storm Runoff in Mountain Watersheds".

Runoff and Sediment Yields From Runoff Plots on Chained Pinyon-Juniper Sites in Utah[1/]

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Running Head: GIFFORD

RUNOFF AND SEDIMENT YIELDS

Footnotes

1/ This study was conducted in cooperation with the Bureau of Land Management under contract 14-11-0008-2837. Journal Paper 1319, Utah Agricultural Experiment Station, Utah State University, Logan.

Highlight

Runoff and sediment production from a chained pinyon-juniper site in both southeastern and southwestern Utah was measured from about June 6 to October 1 over a 5-year period (1968-1972) using .04 hectare (0.11 acre) runoff plots. Treatments evaluated included chained-with-debris-windrowed, chained-with-debris-in-place, and natural woodland. All treatments were fenced to exclude livestock. Runoff events occurred at both sites during only 2 years (1968, 1970) of the study. Results indicate that chained-with-windrowing plots yield from 1.2 to 5 times more water during a runoff event than respective woodland plots. Runoff from debris-in-place plots was equal to or less than that measured from the natural woodland for all storms. Runoff data and sediment indexes indicate that when runoff exceeds about 0.1 cm from the woodland, from 1.6 to 6 times more sediment can be expected from windrowed sites than from adjacent woodland. Sediment yields from debris-in-place sites were similar to those from adjacent unchained woodland for all storms during this study.

Hydrology of the pinyon-juniper (*Pinus* spp.-*Juniperus* spp.) type has received increased interest over the last several years. One of the interesting aspects has been the influence of vegetation modifications on surface runoff and sediment yields. The most common method for modifying pinyon-juniper plant communities is by pulling a large anchor chain between two tractors to uproot the trees. Then, depending on debris disposal techniques, the site is drill or broadcast seeded to other more desirable species. As far as hydrologic performance of the plant community is concerned, the resulting change from woodland to grass-shrubs may significantly alter runoff quantities and resultant sediment discharge.

Studies outlined by Myrick (1971) indicate that chaining and burning of slash, followed by seeding, will cause an increase in runoff for the first couple of years following treatment, then runoff decreases as the new plants establish themselves. He indicates that size of storm may be an important factor in such evaluations. Baker, Brown, and Champagne (1971) report the results of a 25-year storm (September, 1970) on alligator juniper (*Juniperus deppeana*) and Utah juniper (*Juniperus osteosperma*) watersheds on the Coconino National Forest in north central Arizona. In the Utah juniper type, the cabled (treated 1963, slash burned) and chemically treated (100 percent herbicide treated in 1968, no removal or burning) watersheds had 2.0 and 1.3 times, respectively, greater peak discharges than their woodland controls. The response of total runoff on the cabled and chemically treated watersheds was 2.1 and 1.3 times their respective woodland controls. There was no effect from a 5-year old treatment where the trees were felled and left in place. The sediment yield on the cabled juniper watershed was 2465 kg/ha (1.1 tons/acre) while sediment yield from the chemically treated watershed was 112 kg/ha (.05 ton/acre). Again, size

of storm is important. Brown (1971) indicates that, for the various treatments on the same experimental area, there had been no significant changes in water or sediment yields as of November of 1969. Where only select portions of watershed have been treated, increased runoff may not be as noticeable (Collings and Myrick, 1966).

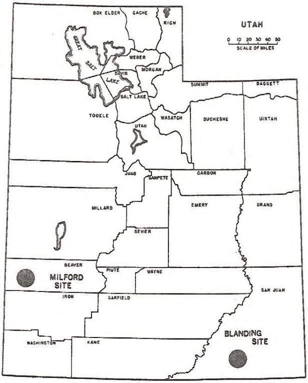
The objective of this study was to evaluate runoff and sediment production from about June 6 to October 1 for a 5-year period from pinyon-juniper sites chained-with-debris-windrowed, chained-with-debris-in-place, and natural woodland, using .04 hectare (.11 acre) runoff plots. It should be emphasized that 5 years is the minimum amount of time required for a study of this type in a semiarid situation. Results and conclusions must therefore be interpreted with this in mind, realizing that no information is available to define whether or not storm characteristics during this 5-year period were typical, below average, or above average for the two study sites.

Site Descriptions and Methods

The study was undertaken at two locations in southern Utah (Figure 1). One site is located about 72 kilometers west of Milford and the other site is located about 70 kilometers west of Blanding.

Chaining treatments were applied at both sites in the fall of 1967, and included chaining with windrowing of debris and double chaining with debris-in-place. The windrowed treatments were drill seeded to crested wheatgrass (Agropyron cristatum) at 9.1 kilograms/ha (8 lbs/acre) and the debris-in-place treatments were broadcast seeded (same rate) to crested wheatgrass. Treatments were applied to from 12 to 16 hectares at each of the two sites. The two sites were then fenced to exclude livestock.

The Milford site is within the Basin and Range Province at an elevation of approximately 2,000 meters. Parent material of the soil is basaltic rock.



UTAH
0 10 20 30 40 50
SCALE OF MILES
BOX ELDER
CACHE
RICH
GREAT
SALT
LAKE
WEBER
MORGAN
DAVIS
SUMMIT
DAGGETT
SALT LAKE
TOOELE
WASATCH
DUCHESNE
UINTAH
UTAH
JUAB
SANPETE
CARBON
MILLARD
EMERY
GRAND
SEVIER
BEAVER
MILFORD
SITE
PIUTE
WAYNE
SAN JUAN
IRON
GARFIELD
BLANDING
SITE
WASHINGTON
KANE

Fig. 1

Soil profile depth is 1.3 meters. Soil texture varies from sandy loam to loam; average rock content (by weight) of the soil is 35 percent; pH averages about 8.0; and organic matter content generally ranges from 1.0 to 2.0 percent. The mature woodland has a canopy cover which averages 15 percent juniper (Juniperus osteosperma---350 trees per hectare) and 10 percent pinyon (Pinus edulis---125 trees per hectare). Brush cover averages seven percent and is composed of big sagebrush (Artemisia tridentata), black sagebrush (Artemisia nova), and broom snakeweed (Gutierrezia sarothrae). Small amounts of phlox (Phlox spp.), Lupine spp., Eriogonium spp., Penstemon spp., and Indian ricegrass (Oryzopsis hymenoides) also occur as part of the understory.

The chaining-with-debris-in-place treatment at Milford currently has a 5 to 10 percent cover of big sagebrush and about the same amount of broom snakeweed. Ground cover consists primarily of weakly developed erosion pavement (30-60 percent), litter (20-45 percent), crested wheatgrass (Agropyron cristatum, 10-15 percent) and the balance bare ground. The chain-with-windrowing treatment currently has from 15 to 50 percent erosion pavement, 30 to 60 percent bare soil, 15 to 35 percent crested wheatgrass, and the balance litter (see Table 1).

The Blanding site is within the Colorado Plateau at an elevation of about 2,150 meters. The parent material of the soil is primarily sandstone, and the soil profile depth is 1.5 meters. Soil texture is mostly sandy loam with few, if any, rocks present; pH averages about 8.0; and organic matter content averages slightly less than 2.0 percent. The mature juniper (500 trees per hectare) and pinyon (200 trees per hectare) canopy coverage averages 24 and 8 percent, respectively. Shrub cover is less than 1 percent and consists of big sagebrush. Bare ground and litter make up the balance. The bare ground category actually includes some cryptogam species present in the top 3 centimeters of soil.

Table 1. Average cover characteristics on .04 hectare runoff plots during 1968-71 at the Milford and Blanding study sites.

	Milford			Blanding		
	(percent cover)[1/]			(percent cover)		
Runoff Plot	Tree[2/]	Shrub	Ground[3/]	Tree	Shrub	Ground
Windrow						
1	0	1	83	0	1	43
2	0	0	36	0	0	33
3	0	0	48	0	0	49
4	0	0	64	0	0	36
5	0	0	26	0	0	40
Woodland Control						
1	21	0	77	48	2	60
2	24	2	87	16	0	22
3	36	0	51	18	1	49
4	29	4	90	24	4	48
5	30	2	93	24	0	49
Debris-in-Place						
1	0	7	94	5	0	71
2	0	8	91	2	0	70
3	1	4	92	2	0	70
4	2	5	93	0	0	72
5	3	11	93	1	0	63

Woodland Control						
1	26	14	84	41	0	45
2	21	14	95	39	0	55
3	18	12	88	34	0	43
4	26	6	90	45	0	61
5	24	4	92	46	0	60

1/ Percent cover in 1968 and 1969 determined from line transect data across each plot at 5.7, 9.9, and 22.2 meters from top end of each runoff plot. During 1970 and 1971 an additional transect at 16.5 meters from top end of each runoff plot was added. Measurements were made in September of each year.

2/ Includes both pinyon and juniper.

3/ Includes grasses, forbs, litter, rock, and erosion pavement.

The chaining-with-debris-in-place treatment at Blanding currently has a ground cover which consists primarily of 25 to 45 percent bare ground, 30 to 60 percent litter, and 12 to 20 percent crested wheatgrass. The chain-with-windrowing treatment currently has from 40 to 65 percent bare ground, 15 to 30 percent litter, and 17 to 25 percent crested wheatgrass cover (see Table 1).

Paired runoff plots .04 hectare (0.11 acre) in size were used during the period of approximately June 5 to October 1 for each of 5 years to study runoff under natural summertime convectional rainfall (Figure 2). The runoff plots were all located prior to the chaining in the fall of 1967 and were installed following the chaining treatments. There were separate controls for each treatment, and five paired runoff plots per treatment, for a total of 20 plots per study site. Plot borders were defined by redwood boards carefully buried in the ground. The collection trench at the bottom of each plot was lined either with 6 ml polyethylene sheeting, 0.3-centimeter asphalt coated plywood, or 30-centimeter half-round corrugated 16-gauge steel, depending on the year. The area immediately below each collection trench was sloped and drained to prohibit flow back into the trench. Redwood boards 5 cm x 10 cm were used as a lip at the front of the trench when plywood or polyethylene sheeting was used. Each collection trench conveyed runoff water to a 30-centimeter Type HS flume with a Stevens Type F water level recorder. The runoff water then dropped into one end of a 2.1 x 0.6 x 0.3 meter aluminum sediment tank with 2.5-centimeter baffles spaced at about 30-centimeter intervals on the bottom. When the tank filled, water ran out the opposite end. The tank simply provided a sediment index for each plot, since there was no attempt to collect all the runoff water. Sediment records are probably biased, therefore, toward the fraction of materials which would settle to the bottom of the tank before being carried

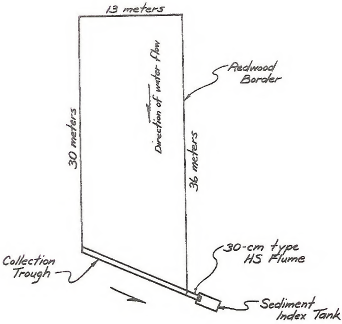

13 meters
Redwood Border
Direction of water flow
30 meters
36 meters
30-cm type HS Flume
Collection Trough
Sediment Index Tank

Fig. 2

out. Because of high rabbit populations at Milford, runoff plots were fenced during the spring of 1970 to exclude rabbits. No fencing was necessary at Blanding.

Two recording 20.3-centimeter (8-inch) raingages and several additional nonrecording 20.3-centimeter raingages are maintained at each site.

Results and Discussion

Runoff events occurred at both sites during only 2 years (1968, 1970) of the study. During 1968, plot construction was still underway, so some data on both runoff and sediment was lost. This was particularly true for sediment records.

Table 2 is a tabulation of runoff events recorded at the Milford site. During 1968 there were three storms of sufficient size and intensity to produce runoff. In all cases the chain-with-windrow plots yielded more water than plots in the woodland. The large amount of runoff recorded on 7-30-68 was a result of moist soils resulting from several consecutive days of small storms, plus high intensity rainfall. The only other runoff event at Milford was recorded on 9-5-70 when 3.73 cm (1.47 inches) of rainfall fell, only a small part of which fell at intensities great enough to cause overland flow. Grass cover on the chain-with-windrowing area had increased significantly by 1970, but there is no evidence to indicate that the increased vegetal cover influenced runoff. From 1.6 to 1.7 times more water was yielded from chained-with-windrowing plots than was yielded from woodland plots for the three larger runoff events at Milford. As for debris-in-place plots, there were no records for 1968 and runoff from the 9-5-70 storm was not significantly different from the natural woodland.

Table 2 also shows runoff events at the Blanding study site. The trend, regardless of year, is the same as at Milford. The only major runoff

Table 2. Average runoff values (area centimeters) from paired runoff plots at Milford and Blanding. Each value is an average of 5 runoff plots.

Date	Total Rainfall (cm)	Woodland	Chain-with windrow	Woodland	Chain-with debris-in-place
		Milford			
7-30-68	4.19	1.96	3.23[2/]	No record	No record
7-31-68	1.52	.30	.48[3/]	No record	No record
8- 8-68	1.78	.05	.18[3/]	No record	No record
9-5-70	3.73	.18	.30[3/]	.18	.05
		Blanding			
7-28-68	1.14	.05	.18[3/]	.05	0
7-30-68	1.14	.08	.23[1/]	.08	.02
8- 5-68	3.68	1.07	1.32[2/]	.81	.36[3/]
8- 3-70	3.23	.13	.63[1/]	.05	0
8- 4-70	2.06	0.30	0.94[2/]	.10	.05
8-16-70[4/]	2.54	0.38	0.69[1/]	.10	0[2/]
8-19-70	1.90	0.41	0.81[2/]	.08	.05

1/ Significantly different from woodland at .05 level of probability

2/ Significantly different from woodland at .10 level of probability

3/ Significantly different from woodland at .20 level of probability

4/ Total precipitation on the windrowed site and adjacent woodland was 2.54 cm while on the debris-in-place site and adjacent woodland total precipitation was 1.93 cm.

event recorded from debris-in-place plots during the entire 5-year study was during the storm of 8-5-68. Even though ground cover (grass, forbs, litter) had increased from 11 percent or less on windrowed plots in 1968 to from 44 to 74 percent in 1970, more water was still being yielded from windrowed plots than from adjacent woodland plots. From 1.2 to 3.5 times more water was yielded from chained-with-windrowing plots than from woodland plots in 1968 and from 1.8 to 5 times more water was yielded from windrowed plots in 1970.

Sediment index records are given in Table 3. The runoff data and sediment indexes indicate that when runoff exceeds about 0.1 cm from the woodland, from 1.6 to 6 times more sediment can be expected from windrowed sites than from adjacent woodland. Sediment yields from debris-in-place sites were similar to those from adjacent unchained woodlands for all storms during this study.

Relationship of Runoff to Infiltrometer Studies

Infiltrometer studies at both the Milford and Blanding study sites has shown that mechanical disturbance on the chain-with-windrowing treatment results in a significant decrease in infiltration rates during select periods of a simulated storm (Gifford, William, & Coltharp, 1970; Gifford, unpublished data; Busby, unpublished data). Part of the reduction in infiltration rates on the windrowed treatments at the Blanding site can be attributed to destruction of cryptogamic soil crusts as a result of mechanical disturbance associated with chaining activities (Loope and Gifford, 1972). Infiltration rates on the chain-with-debris-in-place treatment have not been as greatly affected due to much less mechanical disturbance of surface soils.

Table 3. Sediment index records (kilograms) from paired runoff plots at Milford and Blanding. Each value is an average of 5 runoff plots.1/

Date	Total Rainfall (cm)	Woodland	Chain-with windrow	Woodland	Chain-with debris-in-place
		Milford			
8- 8-68	1.78	0	0	No record	No Record
9- 5-70	3.73	0.5	3.0 4/	0.2	0.4
		Blanding			
7-28-68	1.14	0	0	0	0
7-30-68	1.14	0	0	0	0
8- 5-68	3.68	26.6	41.9	6.2	4.0
8- 3-70 2/ 8- 4-70	3.23 2.06	0.8	3.2	0.3	0
8-16-70 2/ 8-19-70	2.54 3/ 1.90	8.4	19.1 5/	1.7	1.5

1/ Sediment records not available for storms of 7-30-68 and 7-31-68 at Milford.

2/ Sediment index records are combined for storms on these two dates.

3/ Total precipitation for two storms on the windrowed site and adjacent woodland was 4.44 cm while on the debris-in-place site and adjacent woodland the total precipitation was 3.68 cm.

4/ Significantly different from woodland at .10 level of probability.

5/ Significantly different from woodland at .20 level of probability.

Increased runoff from windrowed treatments (as compared to runoff from the woodland) seems logical based on infiltrometer studies. However, why has there been no increase in runoff from the debris-in-place treatment? It appears that infiltration rates at given points on the debris-in-place treatment have been only slightly affected by the chaining activities. Apparently, in these instances, the debris left scattered on the soil surface acts as both retention and detention storage, the magnitude of which is large enough to minimize or nearly eliminate all runoff. The soil under the debris-in-place treatment is not able to absorb water any faster than is the soil under the woodland---it's just held on the landscape until the soil has the time to absorb it. Skau (1961) has estimated that the volume of pits alone (left after uprooting juniper trees) on a Beaver Creek watershed southwest of Flagstaff, Arizona, was enough to reduce surface flow .2 to .7 cm annually. That did not include influence of debris which was left scattered around. The debris-windrowed treatment does not have this added protection, and the potential for plant cover (even under protection from all grazing), under conditions of this study, was not great enough on the windrowed treatment to reduce overland flow below that measured from the woodland.

Figure Titles

Fig. 1. Map showing general location of the two study sites in southeastern and southwestern Utah.

Fig. 2. General layout of .04 hectare (0.11-acre) runoff plots.

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Soil Moisture Patterns on Two Chained Pinyon-Juniper Sites in Utah[1]

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Running Head: GIFFORD AND SHAW

SOIL MOISTURE

Footnotes

1/ This study was conducted in cooperation with the Bureau of Land Management under contract 14-11-0008-2837. Journal paper 1310, Utah Agricultural Experiment Station, Utah State University, Logan.

Highlight

Soil moisture patterns were studied under chaining-with-windrowing, chaining-with-debris-in-place, and natural woodland at one site each in both southwestern and southeastern Utah. Results of the study indicate the greatest moisture accumulation occurred under the debris-in-place treatment (as compared to woodland controls), during the first 6 months of each year at Milford and regardless of season at Blanding. The woodland had the least soil moisture throughout most of each year. Most of the moisture flux took place in the upper 60- to 90- centimeters of soil profile, with only minor changes occurring at greater depths. Differences in soil moisture patterns have been attributed to changes in microclimates due to chaining, different rooting depths and length of growing season, mulching effect of litter on the debris-in-place treatment, and possible differences in snow accumulation. Variation in vegetation density on the chained treatments did not influence soil moisture patterns. There was no evidence of deep seepage on any chaining treatment at either of the two sites.

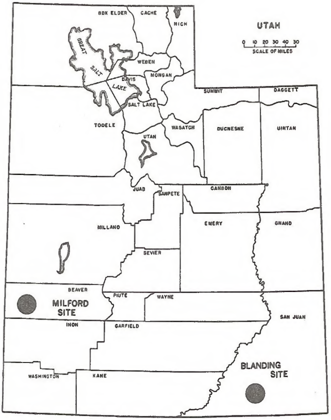
Soil moisture patterns as influenced by vegetation manipulation practices have not received a great deal of attention in the pinyon-juniper (*Pinus edulis*-*Juniperus osteosperma*) type. Only Skau (1964) has published on this aspect, and he found in Arizona that clearing of alligator juniper (*J. deppeana*) and Utah juniper had little effect on water yields as influenced by soil water storage in the upper 60 centimeters of the soil profile. He made nine measurements of soil moisture under cleared versus natural woodland from late June of 1959 through early December of 1960. Calibrated watershed studies described by Brown (1971) and Collings and Myrick (1966) relate to soil moisture patterns, but only indirectly.

The objective of this study was to determine if there were significant differences in soil moisture accumulation among three pinyon-juniper treatments in both southwestern and southeastern Utah. The treatments included natural woodland, chaining-with-debris-in-place, and chaining-with-windrowing.

Site Descriptions and Methods

The soil moisture study was undertaken at two locations in southern Utah (Figure 1). One site is located about 72 kilometers southwest of Milford and the other site is located about 70 kilometers west of Blanding.

The chaining treatments (12 to 16 hectares each) were performed during the fall of 1967 at both sites, and the areas fenced to exclude livestock. Chaining involves pulling a large anchor chain between two tractors to fell the pinyon and juniper trees. The windrowed areas (all debris pushed into windrows--Figure 2) were drill seeded with crested wheatgrass at 9.1 kilograms per hectare and the debris-in-place areas (debris left where it fell--Figure 3) were broadcast seeded at the same rate.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WASATCH
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UTAN
JUAB
SANPETE
CANBON
MILLANO
EMERY
GRAND
SEVIER
BEAVER
MILFORD SITE
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WAYNE
SAN JUAN
INON
GARFIELD
BLANDING SITE
WASHINGTON
KANE

Fig. 1

Fig. 2

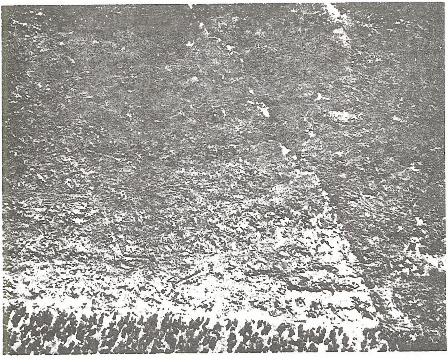


Fig. 3

The Milford site is within the Basin and Range Province at an elevation of approximately 2,000 meters. Parent material of the soil is basaltic rock. Soil profile depth is 1.3 meters. Soil texture varies from sandy loam to loam, and the average rock content (by weight) of the soil is 35 percent. The mature woodland has a canopy cover which averages 15 percent juniper (350 trees per hectare) and 10 percent pinyon (125 trees per hectare). Brush cover averages 7 percent and is composed of big sagebrush (*Artemisia tridentata*), black sagebrush (*Artemisia nova*), and broom snakeweed. Small amounts of phlox (*Phlox* spp.), *Lupine* spp., *Eriogonium* spp., *Penstemon* spp., and Indian ricegrass (*Oryzopsis hymenoides*) also occur as part of the understory.

The chaining-with-debris-in-place treatment at Milford has a 5 to 10 percent cover of big sagebrush and about the same amount of broom snakeweed. Ground cover consisted primarily of weakly developed erosion pavement (30-60 percent), litter (20-45 percent), crested wheatgrass (*Agropyron cristatum*, 10-15 percent) and the balance bare ground. The chain-with-windrowing treatment had from 15 to 40 percent erosion pavement, 30 to 60 percent bare soil, 15 to 35 percent crested wheatgrass, and the balance litter. Cover percentages are taken from line transect data collected on each treatment. Annual precipitation during the three-year study (as measured on site) averaged about 240 mm.

The Blanding site is within the Colorado Plateau at an elevation of about 2,150 meters. The parent material of the soil is primarily sandstone, and the soil profile depth is 1.5 meters. Soil texture is primarily sandy loam with few, if any, rocks present. The mature juniper (500 trees per hectare) and pinyon (200 trees per hectare) canopy coverage averages 24 and 8 percent, respectively. Shrub cover is less than 1 percent and consists

of big sagebrush. Bare ground and litter make up the balance. The bare ground category actually includes some cryptogam species present in the surface 3 cm of soil.

The chaining-with-debris-in-place treatment at Blanding has a ground cover which consists primarily of 25 to 45 percent bare ground, 30 to 60 percent litter, and 12 to 20 percent crested wheatgrass. The chain-with-windrowing treatment has from 40 to 65 percent bare ground, 15 to 30 percent litter, and 17 to 25 percent crested wheatgrass cover. Average annual precipitation during the two-year study was nearly identical to that measured at Milford, 240 mm.

Soil moisture measurements at both the Milford and Blanding sites were taken with a Troxler depth moisture probe (Model 56A, Model 105A) and scaler Model 399C). Neutron measurements were taken at 30 centimeter increments starting 15 centimeters below the soil surface. Compaction of soil around access tubes was minimized by using a small platform for support while taking neutron readings at each tube. During the period June through September soil moisture was measured approximately once every two to three weeks. Measurements were less frequent other parts of the year. Three years of data from the Milford site and two years of data from the Blanding site are presented here.

Fifteen access tubes were installed in each of the three treatments (natural woodland, chained-with-debris-in-place, and chained-with debris-windrowed) at each site. Separate woodland controls for each treatment were maintained at Milford since the two chaining treatments were some distance apart. Therefore, at Milford, the total number of access tubes was increased to 60. The access tubes were installed to a depth of 120 centimeters with a rock drill at the Milford site and to a depth of 150 centimeters with soil auger at the Blanding site.

Access tubes were located throughout each 12-to 16-hectare woodland and chain-with-debris-in-place treatment, the final exact location of each tube being determined by the required soil profile depth. On the debris-windrowed treatment the access tubes were generally installed between each set of windrows in the pattern shown in Figure 2. Given two windrows, access tube X_1 would be 5 to 7 meters from the first (uppermost) windrow, X_2 would be one-third to one-half the distance between the two windrows, and X_3 would be approximately 2/3 the distance from the first windrow. On the next set of windrows, this pattern would be reversed, etc. Data were analyzed, after preliminary examination, using standard analysis of variance techniques for a completely randomized design.

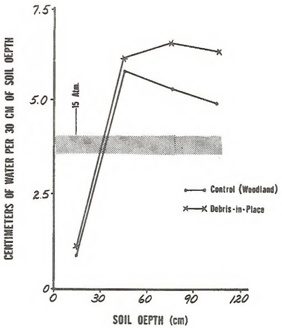
Jackrabbit populations on the Milford site were very high during the study. To prevent grazing, rabbit-proof fencing was installed to enclose a 4.5-meter-square area around each access tube on the chained areas. The fences were taken down during each winter to prevent a snow fence effect around the access tubes.

The level of probability used for defining differences in this study was 10%. It was felt that studies utilizing fewer replications per treatment at two distinct locations within the state was preferred to a more intensive study at a single site. As a result, the findings of this study can probably be extrapolated to other sites with a higher degree of reliability, but there is still the 1 in 10 chance that noted differences in soil moisture patterns among treatments are not real.

Results

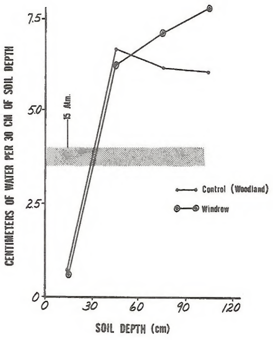
Milford

Figures 3 and 4 show average centimeters of water per 30 centimeters of soil depth for a two-year period for each chaining treatment and the



7.5
5.0
2.5
0
CENTIMETERS OF WATER PER 30 CM OF SOIL OEPTH
15 Atm.
Control (Woodland)
Debris-in-Place
0
30
60
90
120
SOIL OEPTH (cm)

Fig. 4



CENTIMETERS OF WATER PER 30 CM OF SOIL DEPTH
7.5
5.0
2.5
0
15 Atm.
Control (Woodland)
Windrow
0
30
60
90
120
SOIL DEPTH (cm)

Fig. 5

respective woodland control. The trend was the same over a three-year period. Averaged over all sampling dates, the debris-in-place treatment had more soil moisture throughout the 120-centimeter profile than the woodland. The four soil depths (30, 60, 90, and 120 centimeters) within the debris-in-place treatment and within the woodland were all different from one another in moisture content.

In the debris-windrowed treatment, the amount of soil moisture in the surface 30 centimeters was very similar to the amount found in the woodland. At the 30- to 60-centimeter soil depth the woodland had more soil moisture than the debris-windrow treatment. The debris-windrowed treatment had more soil moisture than the woodland in the last 60 centimeters of the 120-centimeter soil profile. The four soil depths (30, 60, 90, and 120 centimeters) within the debris-windrowed treatment and within the woodland all differed from one another in moisture content except for the 90-centimeter and 120-centimeter depths in the woodland. Most of the moisture flux took place in the upper 60- to 90-centimeters of soil profile, with only minor changes occurring at greater depths.

In averaging data over all four sampling depths for each sampling date, it was obvious that the debris-in-place treatment consistantly had more soil moisture during the first half of each year than the adjacent woodland (Table 1). This trend was not so pronounced in comparing the windrow treatment to the woodland. The debris-in-place treatment had more soil moisture than the woodland on 14 of 28 measuring dates. The debris-windrowed treatment had more soil moisture than the woodland on 9 of 28 measuring dates; the differences occurred primarily during the first half of each year.

The greatest difference between chained treatments and woodland occurs during the March-April period, when soil moisture storage reaches an annual peak. During all three years of the soil moisture study there was a slight

Table 1. Average centimeters of water per 30 cm of soil profile on various dates at Milford study site[1/]

Date	Woodland	Chain-Windrow	Woodland	Chain Debris-in-Place
9-24-69	4.57	5.00	3.78	4.44
12-15-69	5.16	5.56	4.17	5.56[a]
3-07-70	5.89	5.97	5.36	6.50[a]
3-28-70	6.91	7.47	6.76	7.37
4-21-70	5.28	6.71[a]	5.31	6.43[a]
5-22-70	5.41	6.05	4.88	6.08[a]
6-23-70	4.55	5.33[a]	4.01	5.26[a]
7-24-70	4.47	5.31[a]	4.09	4.65
8-04-70	4.65	4.95	4.06	4.78
8-18-70	4.80	5.36	4.09	4.78
9-04-70	5.41	5.56	4.47	5.08
10-03-70	4.88	4.70	3.66	4.24
3-10-71	5.38	6.22[a]	4.47	5.61[a]
6-08-71	4.95	6.02[a]	4.34	5.18[a]
6-18-71	4.98	5.74[a]	3.94	4.67[a]
7-21-71	4.42	4.95	3.51	4.29[a]
8-05-71	4.62	4.90	3.68	4.01
8-17-71	4.47	4.62	4.17	4.44
9-05-71	4.39	4.57	3.78	4.29
11-11-71	5.31	6.12[a]	4.65	5.38[a]
2-19-72	7.21	7.77	6.07	6.98[a]
4- 1-72	5.26	6.17[a]	4.47	5.46[a]
5-28-72	4.42	5.41[a]	3.84	4.57[a]
6-20-72	4.32	4.93	3.76	4.47[a]
7-07-72	4.42	4.80	3.48	3.84

Date	Woodland	Chain-Windrow	Woodland	Chain Debris-in-Place
8-05-72	4.09	4.44	3.38	3.63
8-29-72	5.23	5.33	3.71	4.24
9-17-72	4.17	4.42	3.35	3.71

1/ All values with superscript "a" are different (p>0.1) from respective woodland controls.

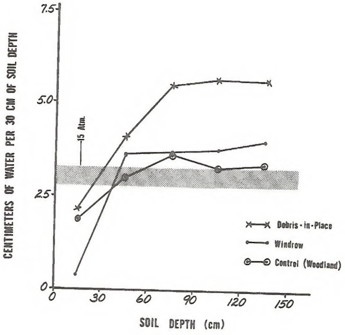
increase in soil moisture caused by convectional thunderstorms from July through September.

Blanding

Results at the Blanding site are very similar to those found at Milford. Figure 5 shows the average centimeters of water per 30 centimeters of soil depth for one year for each chaining treatment and the woodland control. Analysis of two years of data gave the same relationships. The debris-in-place treatment had more soil moisture throughout the 150-centimeter soil profile than either the debris-windrowed treatment or woodland. The woodland control had more soil moisture in the surface 30 centimeters of soil profile than the debris windrowed treatment. In the remaining 120 centimeters of soil profile, the debris-windrowed treatment had significantly more soil moisture than the woodland. Table 2 shows the average centimeters of water per 30 centimeters of soil profile on various dates for the different chaining treatments and woodland. The debris-in-place always had more soil moisture than the woodland, and the debris-windrowed treatment had more soil moisture than the woodland on 11 of the 23 measuring dates.

Discussion

The different soil moisture patterns could have been a result of differing vegetation densities rather than a result of the chaining treatments. This factor was examined at each study site by using a point frame 150 centimeters in length which had 25 equally spaced pins and which was fastened directly to a given access tube. One hundred points were recorded around each access tube, 25 in each of the four cardinal directions, during September of 1971. Resultant data indicated the density of potential



CENTIMETERS OF WATER PER 30 CM OF SOIL DEPTH
7.5
5.0
2.5
0
15 Atm.
Debris-in-Place
Windrow
Control (Woodland)
0
30
60
90
120
150
SOIL DEPTH (cm)

Fig. 6

Table 2. Average centimeters of water per 30 cm of soil profile on various dates at Blanding study site. 1/

Date	Woodland	Chain-Windrow	Chain, Debris-in-Place 2/
7-26-70	2.34	2.64	3.81
8-08-70	2.64	3.10[a]	4.47
8-22-70	2.95	3.48[a]	4.65
9-01-70	2.77	3.12	4.42
9-14-70	2.77	3.18[a]	4.44
11-27-70	2.77	3.58[a]	4.57
4-03-71	3.10	3.78[a]	4.90
5-20-71	2.72	3.02	4.34
6-08-71	2.74	3.05	4.44
6-21-71	2.57	2.79	3.71
7-08-71	2.62	3.12[a]	3.91
7-20-71	2.62	2.84	4.19
8-02-71	2.90	3.07	4.29
8-14-71	3.35	3.05	4.06
11-04-71	3.30	3.99[a]	5.74
2-26-72	4.29	4.93[a]	5.69
4-13-72	3.23	4.09[a]	5.11
6-09-72	2.79	3.23[a]	4.47
6-24-72	2.82	3.48[a]	4.52
7-11-72	2.72	3.07	4.22
7-20-72	2.69	2.90	4.22
8-03-72	2.69	3.05	3.99
9-12-72	2.62	2.90	3.81

1/ All values with superscript "a" are different ($p>0.1$) from respective woodland controls.

2/ Debris-in-place soil moisture values are all different ($p>0.1$) from soil moisture values on windrow treatment.

transpiring plant material. Regression analysis was used to determine the influence of vegetation density--on each chaining treatment--on soil moisture at three depths (15, 45, and 75 centimeters) on each of three dates during 1971. At Milford the debris-in-place treatment and the debris-windrowed treatment averaged 15.6 and 28.0 percent, respectively, live vegetal ground cover around each access tube. The debris-in-place treatment and the debris-windrowed treatment at Blanding averaged 15.8 percent and 23.0 percent, respectively, live vegetal ground cover around each access tube. Results of the analysis indicated that vegetation densities as measured in this study had no measureable effect on soil moisture patterns.

Differences in soil moisture patterns are due in part to differences in microclimates created by chaining as well as differences in rooting depths and length of growing season. On the debris-in-place treatments, wind speeds are probably reduced near the soil surface due to a boundary effect caused by scattered debris. Lack of this uniform boundary effect on the debris-windrowed treatment causes increased wind turbulance and therefore greater vapor pressure gradients and increased evapotranspiration.

The mulching effect of litter on the debris-in-place plots could also be a significant factor. At Milford, litter averaged 32 percent on the debris-in-place treatment and only 7 percent on the debris-windrowed treatment. The debris-in-place treatment at Blanding averaged 54 percent litter cover as compared with only 22 percent litter cover on the debris-windrowed treatment. Increased litter would mean decreased soil surface temperatures and decreased evaporation.

Differences in snow accumulation as a result of chaining may also account for some of the differences in soil moisture patterns between chained treatments. Limited data indicates the possibility of greater snow accumulation on debris-in-place plots, especially during periods with high snowfall.

As previously mentioned, most of the moisture flux took place in the upper 60- to 90-centimeters of soil profile with only minor changes occurring at greater depths. Less soil moisture at the 90-, 120-, and 150-centimeter depths in the woodland is due in part to deeper root penetration by the pinyon and juniper trees. The crested wheatgrass roots are concentrated in the surface 45 centimeters of soil profile while juniper and pinyon roots are concentrated in the upper 90 centimeters of soil profile with sinker roots that penetrate even further. This, combined with a seasonal growth of crested wheatgrass as compared with pinyon and juniper which may transpire a major part of the year, would contribute to less soil moisture in the woodland.

Examination of forage yield data indicates that total yield of grasses, forbs, and brush is as much, or slightly greater, on the debris-in-place treatments than on the windrowed treatments. However, there is no evidence that surface soil moisture conditions have been improved enough on the debris-in-place treatments to affect seedling establishment. It is speculated that young trees missed in the chaining process and also deep-rooted shrub species on debris-in-place treatments may benefit most from increases in soil moisture, especially at soil depths beyond 60 centimeters.

And finally, during the course of this study, there was no indication of any excess moisture for eventual deep seepage. Areas similar to the Milford site which have had springs develop following chaining are areas which have zones of subsurface flow as a result of snowmelt at elevations above the chaining project. The subsurface flow, which was normally consumed by the pinyon-juniper woodland, is not entirely consumed (transpired) under a grass cover. As a result, springs may develop or increase in flow as a result of the chaining. However, based on this study, the water is apparently not due to on-site additions to soil moisture.

Figure Titles

Fig. 1. Map showing general location of the two study sites in southeastern and southwestern Utah.

Fig. 2. Aerial view of chain-with-windrowing treatment at Blanding study site showing location of soil moisture access tubes (see text) between windrows. Barely visible is one of several .04-hectare runoff plots being used for other studies. Photo scale is 1 cm = 21 meters.

Fig 3. Aerial view of chain-with-debris-in-place treatment at Blanding study site. Photo scale is 1 cm = 21 meters.

Fig. 4. Average centimeters of water per 30 centimeters of soil depth for debris-in-place treatment and adjacent woodland at Milford.

Fig. 5. Average centimeters of water per 30 centimeters of soil depth for debris-windrowed treatment and adjacent woodland at Milford.

Fig. 6. Average centimeters of water per 30 centimeters of soil depth for all treatments at Blanding.

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Sap Velocities in Pinyon and Juniper Trees and Their Relationship to Measured Environmental Factors

Connor B. Shaw and Gerald F. Gifford[1/]

Water use by juniper (Juniperus osteosperma) and pinyon (Pinus edulis) has not received a great deal of attention in the past, despite the fact that much of the Southwest is covered with pinyon-juniper vegetation. In Utah, about 12.7 million acres or 23.4 percent of the land mass supports some expression of this vegetative type (Dortignac, 1960).

Most plant-water related studies in the pinyon-juniper type have been concerned with soil moisture patterns or stream flow as a result of vegetation manipulation practices (Skau, 1964; Collings and Myrich, 1966; Brown, 1970). Few studies have involved direct measurement of water loss or water movement in either pinyon or juniper trees (Decker and Skau, 1964; Jameson, 1966).

The objective of this study was to examine sap velocities (one indicator that transpiration is taking place) in both pinyon and juniper trees and to relate the measured velocities to nearby environmental factors. In this paper, velocity of a heat pulse within either a pinyon or juniper tree as influenced by flow of sap was used to define sap velocities. Heat-pulse velocity, the technically correct term, is used interchangeably with sap velocity.

Methods

The study was undertaken at two locations in southern Utah (Figure 1). One site is located about 72.5 kilometers west of Milford and the other site is located about 72.5 kilometers west of Blanding.

The Milford site is within the Basin and Range Province at an elevation of approximately 2,000 meters. Parent material of the soil is basaltic rock. The soil profile dpeth is 1.3 meters. Soil texture varies from sandy loam to

Abstract

Sap velocities in pinyon (*Pinus edulis*) and juniper (*Juniperus osteosperma*) trees in southeastern and southwestern Utah were studied for 1 year using the heat-pulse technique. Measured velocities were related to nearby environmental factors. Pinyon trees had significantly higher sap velocities when soil moisture was readily available, but as soil moisture stress increased the juniper trees had significantly higher sap velocities. Sap velocity was independent of the dry weight of green biomass within both pinyon and juniper trees. From 90.5 to 99.0 percent and from 66.0 to 99.0 percent of the variability in sap velocities in pinyon and juniper trees, respectively, on a diurnal basis, could be accounted for by using an 8-variable multiple regression equation. Amount of explained variability in sap velocities was reduced markedly when sap velocities and environmental data were pooled over all sampling dates.

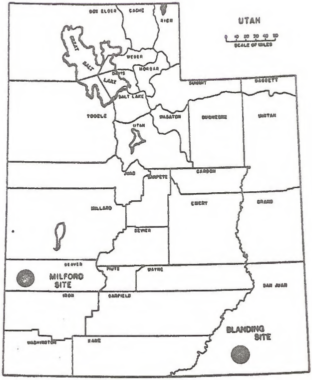

Figure 1. Map of Utah showing location of study sites.

loam, and the average rock content (by weight) of the soil is 35 percent. Woodland canopy cover averages 15 percent juniper and 10 percent pinyon. Brush cover averages 7 percent and is composed of big sagebrush (*Artemisia tridentata*), black sagebrush (*Artemisia nova*), and rabbitbrush (*Chrysothamnus viscidiflorus*). Small amounts of phlox (*Phlox hoodii*), *Lupine* spp., *Eriogonium* spp., *Penstemon* spp., and Indian rice grass (*Oryzopsis hymenoides*) also occur as part of the understory. Annual precipitation is about 30 cm.

The Blanding site is within the Colorado Plateau at an elevation of about 2,150 meters. The parent material of the soil is primarily sandstone, and the soil profile depth is 1.5 meters. Soil texture is primarily sandy loam with few, if any, rocks present. Juniper and pinyon canopy coverage averages 24 and 8 percent, respectively. Shrub cover is less than 1 percent and consists of big sagebrush. Bare ground and litter make up the balance. The bare ground category actually includes some cryptogam species present in the surface 3 cm. of soil. Annual precipitation is about 30 cm.

All sap velocities were measured by the heat-pulse technique of Marshall (1958), as modified by Swanson (1967) and Gifford and Frodsham (1972).

A 3-0-8-mm probe spacing was used, and two sets of probes were installed in the stem (sapwood) of each tree at a distance of from 50 to 75 cm above the soil surface. Tree diameters at 30 cm height ranged from 25 to 50 cm with a mean of 37 cm. A Hewlett-Packard 419A DC Null Voltmeter was used as a null detector for temperature measurements. Five plants of each species were measured each hour on select days during a year from before sunrise to after sunset. The minimum detectable sap velocity was 3 cm/hr.

Several environmental parameters were measured near the trees. Incoming solar radiation was measured with a Yellot-Sol-A-Meter (silicon cell) coupled to a Rustrak Model 88 12 v dc MV recorder. Temperatures were measured with shielded mercury-in-glass thermometers. Belford model

9924A totalizing anemometers were used for taking wind measurements and a sling psychrometer was used for taking relative humidities. Soil moisture was measured with a Troxler depth moisture probe (model 105 A) and scaler (Model 399 C).

The green transpiring biomass of each tree was determined according to modification of the method described by Darling (1967). Five pinyon and five juniper trees were sampled from Milford and Blanding combined. After the diameters were taken at the 30 cm height, the trees were cut down and all living green biomass and twigs were removed. Following drying, 15 subsamples (220 gm/sample) of material were separated into twigs and dry green biomass. The average value for dry green biomass was used to adjust the total dry weight of material harvested from each tree.

The following parameters were examined on both a daily and seasonal basis in a step-wise multiple regression analysis for their influence on sap movement:

X_1 Wind speed at 30 cm height

X_2 Wind speed at mid-canopy (about 3.5 m)

X_3 Wind speed at top of canopy (about 7.0 m)

X_4 Soil temperature at 60 cm soil depth

X_5 Air temperature at 30 cm height

X_6 Air temperature at mid-canopy

X_7 Air temperature at top of canopy

X_8 Incoming shortwave radiation

X_9 Relative humidity at 30 cm height

X_{10} Relative humidity at 3.5 m height

X_{11} Relative humidity at 7 m height

Environmental factors were measured on an hourly basis, as were sap velocities.

Results

Species Differences

Tables 1 and 2 show average sap velocities in cm/hr on various dates for pinyon and juniper at Milford and Blanding. At Milford, pinyon trees had significantly higher sap velocities on two dates during August 1970 and one date during April 1971. Juniper had significantly higher sap velocities on several dates during June through August, 1971. Results were similar at Blanding in that pinyon had significantly higher sap velocities on two dates during August and September of 1970. Juniper had significantly higher sap velocities on six dates during June through August of 1971.

Both pinyon and juniper roots are concentrated in the upper 90 cm of soil profile. Examination of Blanding soil moisture data from the 0-30 cm, 30-60 cm, and 60-90 cm depths indicated that sap velocities were higher in juniper trees when total soil moisture was low (approximately 6.1 cm in 90 cm of soil). As total soil moisture exceeded approximately 7.6 cm, then pinyon trees had significantly higher sap velocities. This trend was not readily apparent, however, at the Milford site.

Daily Sap Velocity Patterns

Eleven of 15 measuring dates at Milford had significant hourly fluctuations in sap velocity. At Blanding, 8 of 13 measuring dates had significant hourly fluctuations in sap velocity. Figure 2 is an example of average sap velocities for each species on two dates at Milford. On August 6, 1970, there were significant fluctuations in sap velocity while on June 23, 1971, there were no significant fluctuations. Figure 3 is the same type of example from Blanding. On September 2, 1970, there

were significant fluctuations while on June 14, 1971, there were none.

Sap Velocity vs. Green Biomass

Darling's (1967) studies on pinyon and juniper trees show that as the diameter at the 30-cm height increases, so does the weight of the green biomass within the tree. Differences in amount of green biomass between or within species could influence sap velocity.

Figure 4 shows the relationship of dry weight of green biomass to the diameter of 30 cm height of pinyon and juniper trees from both the Milford and Blanding study sites. There was no obvious reason for separating either species or sites. A graphical analysis of sap velocities vs tree diameters at 30 cm height on select dates indicated that within the range of tree diameters encountered in this study, sap velocity was independent of the dry weight of green biomass within the tree.

Sap Velocities and Nearby Environment

Daily Patterns

Preliminary screening of variables and their relation to sap velocity revealed that three factors (X_2, X_6, X_{10}) at approximate mid-canopy height could be eliminated, thereby increasing the degrees of freedom in the stepwise multiple regression analysis. The remaining environmental factors accounted for 90.5 to 93.0 percent of the variability in sap velocity of pinyon and between 68.4 to 96.0 percent of the variability in sap velocity of juniper at the Milford site. The importance of any one variable varied considerably from date to date and depending on tree species. The factors and the range in variance explained are as follows (Milford site):

Variable	Percent Variance Explained: Pinyon	Percent Variance Explained: Juniper
X_1	3.5-27.9	0.1-3.0
X_3	0.0-16.6	0.2-10.5
X_4	1.0-23.4	0.1-24.2
X_5	0.3-84.5	0.0-4.9

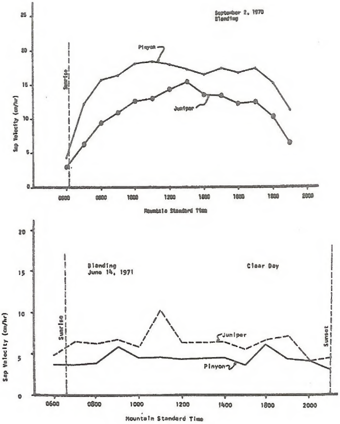

Figure 3. Average sap velocities for pinyon and juniper on two dates at Blanding.

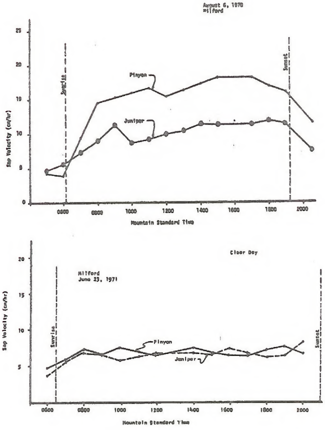

Figure 2. Average sap velocities for pinyon and juniper on two dates at Milford.

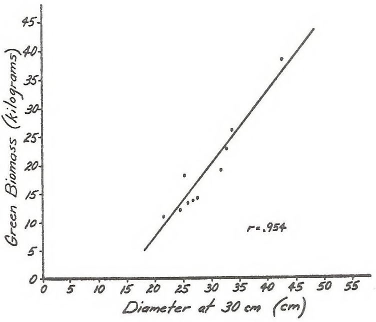

Figure 4. Relationship of dry green biomass to diameter at 30 cm height for both pinyon and juniper trees. Equation of the line is $Y = -18.67 + 1.28(X)$.

X_7	0.2-19.5	20.2-84.9
X_8	0.3-9.5	3.2-17.9
X_9	0.9-42.9	0.2-10.5
X_{11}	1.0-4.0	0.1-1.2

At the Blanding site, environmental factors accounted for 92.1 to 99.0 percent of the variability in sap velocity of pinyon and for 66.0 to 99.0 percent of the variability in juniper. As at Milford, the importance of a given factor varied from date to date and depended on tree species. The factors and the range in variance explained are as follows:

Variable	Percent Variance Explained	
	Pinyon	Juniper
X_1	0.0-1.0	2.6-11.4
X_3	0.0-10.6	1.6-16.2
X_4	0.3-14.0	0.1-5.9
X_5	0.6-13.6	0.3-84.6
X_7	0.0-84.6	0.6-17.2
X_8	0.8-66.6	0.3-28.6
X_9	0.0-3.8	0.1-6.8
X_{11}	0.3-8.5	0.0-19.2

All Data Pooled

Results of pooling data over all sampling dates do not account for much of the variability in sap velocity. At Milford, the 11-variable multiple regression model explained 37.7 and 26.7 percent of the variability associated with sap velocity in juniper and pinyon trees, respectively. Five of 11 variables explained more than 1 percent of the variability in sap velocity of pinyon trees, while 4 of 11 variables explained more than 1 percent of the variability in juniper trees at Milford. These variables and their relative importance are given below:

Variable	Percent Variance Explained	
	Pinyon	Juniper
X_1	1.4	
X_2	3.2	
X_5		2.3
X_8	15.0	7.2
X_9		25.8
X_{10}	1.1	
X_{11}	3.2	1.1

At Blanding, the 11-variable multiple regression model explained 31.9 and 29.8 percent of the variability associated with sap velocities in pinyon and juniper trees, respectively. Five of 11 variables explained more than 1 percent of the variability within both species. These variables and their relative importance are given below:

Variable	Percent Variance Explained: Pinyon	Juniper
X_1	15.1	6.2
X_2		1.6
X_3	1.8	10.8
X_6	3.1	
X_7	1.3	5.3
X_{10}	8.6	2.1

Conclusions

Sap velocities in both the pinyon and the juniper trees at both study sites were greatest during the first 8 months of the study. Soil moisture was greatest during this period. There was a definite trend toward higher sap velocities in pinyon (as compared with juniper) when ample soil moisture was present. As soil moisture stress increased, sap velocities were higher in the juniper trees, though sap velocities in both species were decreased. The exact nature of response to moisture stress was not defined since roots of the two species were not confined to a known volume of soil.

Significant hourly fluctuations in sap velocity occurred on approximately 68 percent of the measuring dates at the two sites. Size of tree did not influence sap velocities as sap velocity was independent of the dry weight of green biomass within a given tree.

Nearby environmental factors accounted for up to 99.0 percent of the variability in sap velocities of both pinyon and juniper trees on a diurnal basis. Environmental factors generally accounted for a greater amount of variability in sap rates of pinyon than in sap rates of juniper. This is somewhat of interest because Jameson (1966) found no correlation of moisture

content for pinyons with meteorological conditions. He concluded that pinyon leaves have some mechanism to retard the rate of moisture loss that would otherwise occur during summer days, while the mechanism in junipers is not fully adequate. This study would suggest just the opposite, perhaps, with respect to the pinyon trees. The importance of any one environmental factor varied considerably from date to date, between sites, and between tree species.

Pooling data over all sampling dates resulted in large reductions in amount of explained variability associated with sap velocities in both the pinyon and the juniper trees. As with the diurnal trends, importance of any one environmental factor varied between sites and depending on tree species.

Footnotes

1/ The authors are, respectively, Graduate Research Assistant and Associate Professor, Range Watershed Science, College of Natural Resources, Utah State University, Logan, 84322. This study was in cooperation with the Bureau of Land Management, Contract 14-11-0008-2837. Journal Paper No. 1300, Utah Agricultural Experiment Station, Logan.

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TABLE 2. Average sap velocities in juniper and pinyon trees on various dates at Blanding.

	Sap Velocity (cm/hr) 1/	
Date	Juniper	Pinyon
8-24-70	11.53	15.47**
9-2-70	11.23	15.75**
11-27-70	3.65	3.95
11-28-70	3.76	3.88
4-3-71	10.54	10.30
6-12-71	3.91	3.72
6-13-71	4.36	3.84
6-14-71	6.07**	4.20
6-25-71	4.64**	3.68
6-27-71	4.64	4.18
7-9-71	4.58**	3.98
7-10-71	4.42*	3.72
8-7-71	3.52**	3.20

*Significant at .05 level of probability

**Significant at .01 level of probability

1/ Each value represents an average of 4 or 5 trees of each species.

TABLE 1. Average sap velocities in juniper and pinyon trees on various dates at Milford.

Date	Sap Velocity (cm/hr) 1/	
	Juniper	Pinyon
8-6-70	9.34	12.45**
8-20-70	5.71	9.67**
4-10-71	11.49	12.74*
6-22-71	6.45	6.23
6-23-71	6.44	6.92
6-24-71	7.12	6.42
7-7-71	7.79**	6.28
7-20-71	5.68**	4.57
7-21-71	5.35	4.90
7-22-71	6.62*	5.01
8-3-71	6.38**	4.79
8-4-71	7.47**	5.78
8-5-71	6.88	8.22
9-6-71	6.67*	5.85
9-7-71	6.95*	5.59

*Significant at .05 level of probability

**Significant at .01 level of probability

1/ Each value represents an average of 4 or 5 trees of each species.

PRELIMINARY DRAFT
SUBJECT TO REVISION

Improved Prediction of Storm Runoff
in Mountain Watersheds

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FEB 27 1973

REVIEW?

I. Introduction

A frequent problem in applied hydrologic engineering or watershed management is the estimation of storm flows from events of given duration and design frequency. Such information is used in sizing storages and diversions, and as a point of departure for estimating peaks via a unit hydrograph technique.

Faced with a need for a uniform procedure to apply on a nationwide basis, a technique was devised about 20 years ago by U.S.D.A. Soil Conservation Service (2). Millions of dollars worth of structures have since been designed in accordance with the technique. In addition, it has also been adopted by a wide circle of non-agency practitioners in the design of storm drains, culverts, etc., and for better or worse, is a widely used tool. Its popularity beyond the original intention is an indication of the need for such. Although a strong point of the methodology is the ability to accomodate changes in land use and condition, the mere act of standardization and institutionalizing the procedure has promoted its use on an international scale.

II. Existing Methodology

The existing methodology consists essentially of two (2) elements: 1) a prediction formula for storm runoff as a function of precipitation and land condition; and 2) a uniform technique for compiling hydrographs for complex storms. The major innovations and new concepts are in element 1). They will be covered in some detail below.

Using a storm precipitation and storm runoff plot as shown in Figure 1, "S" is defined as the maximum possible difference that could occur between precipitation and runoff. Conceptually, this is the maximum possible on-land storage and water use during a storm. It is approached as the storm precipitation becomes greater.

Next, the following proportion is hypothesized:

$$\frac{Q}{P} = \frac{P - Q}{S} \qquad (1)$$

The origin of this equality is obscure, but it can be reasoned that it becomes more valid as P becomes larger. (As an interesting aside, the expression $Q/P = P/(P + S)$ could also be used as a starting point in equation (1). It also solves to equation (2), but lends itself to a simpler geometric interpretation.)

Equation (1) is then solved for Q to give

$$Q = \frac{P^2}{P + S} \qquad (2)$$

Examination of this expression indicates that any P greater than Q will provide a positive runoff. Reasoning that an initial abstraction (Ia) is required before any runoff can begin, this is subtracted from the precipitation, so that

$$Q = \frac{(P - Ia)^2}{P + S - Ia} \qquad (3)$$

The equation is then simplified by substitution of

$$Ia = 0.2S \qquad (4)$$

a relationship which was found as representative from a number of studies of watershed hydrology throughout the country. Equation (3) then becomes

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad P > 0.2S \qquad (5)$$

This is the SCS runoff equation, giving Q as a function of S and P, both in inches. The relationship is further coded by transforming S through

$$CN = \frac{1000}{10 + S} \qquad (6)$$

where CN is called the "curve number". It is, apparently, dimensionless. Note that it varies from 0 (at $S \to \infty$) to 100 (at $S \to 0$). Thus, at CN = 100, P = Q; and at CN = 0, Q = 0 for all P. It is <u>not</u> a percentage representation of the rational runoff coefficient.

Thus, for a given CN (held to be a "constant"-or nearly so) for a given land condition or description, S is calculated, and then Q (Eq5) from the given precipitation. This figure is then used in further design steps, such as hydrograph calculation.

It is worthwhile to review the two major assumptions made in the derivation: These are:

1. The original proportion is valid: i.e., Q/P = (P - Q)/S.
2. Ia exists and = 0.2S.

An accounting of the effect of the initial moisture situation or CN can also be made: adjusting CN up or down in accordance with the 10-day antecedent rainfall. While important in design work, it will not be covered here. It will be evident that in the work to follow, it does not have sufficient variety to affect the outcome in the cases studied.

III. Examination of Field Date

Any watershed storm data (precipitation and runoff) can be applied to equations (5) and (6) to calculate the CN for that event, watershed, and land condition. Equation (5) is solved for S as follows:

$$S = 5\left\{(P + 2Q) - \sqrt{4Q^2 + 5PQ}\right\} \tag{7}$$

and S is then inserted into equation (6) to calculate CN.

It is useful now to determine the curve number for which there is no runoff. Setting $Q = 0$ in equation (7) leads to $S = 5P$, and inserting this into equation (6) produces $CN = 100/(1 + P/2)$. Calling this CN_o, it represents a lower limit of curve number definition: any less precipitation will not satisfy Ia, and thus no runoff will occur; similarily, any smaller curve number will indicate an Ia greater than the precipitation, another no-runoff situation.

If a watershed and land condition has a characteristic hydrologic index represented by CN, it should be a constant, or nearly so, for a variety of input situations. Tables 1 & 2 give data for four small western mountain watersheds for which the curve numbers were determined. In all four cases, CN is found to be very dependent upon storm precipitation. Figures 2 & 3 show the data plotted for these areas, with curves of best fit superimposed.

It should be noted on Figures 2 and 3 that the data fit does not account for differences in antecedent soil moisture: ~~ay~~ any influence would fall within the residual variance. Although this matter was not explored further, such findings would imply that either 1) antecedent soil moisture has but a small effect, or 2) it was a constant (and low?) value in all storms studied.

IV. A Suggested Change

In viewing Figures 2 and 3, it was hypothesized that the points "ride" above CN_o by a near constant proportion of the difference between the upper limit ($CN = 100$) and CN_o. This proportion, k, could then define CN for a given P (i.e., CN_p) such that

$$CN_p = CN_o + k(100 - CN_o) \tag{8}$$

Since CN_o is the CN at which runoff begins for a given P, it can be seen that Eq (8) is an expression for CN as a function of P and the proportion k. Substituting $CN_o = 100/(1 + P/2)$ into (8) and simplifying gives

$$CN_p = 100\left[\frac{2 + kP}{2 + P}\right] \tag{9}$$

For the four watersheds used, the value of "k" was determined by a least squares procedure. The r^2 and S_e values (see Table 2) indicate the concept works well in accounting for variations in CN with P.

It should be noted that as P becomes greater, CN_p becomes more constant. It can be shown that

$$\lim_{P \to \infty} CN = 100\left[\frac{2 + kP}{2 + P}\right] = 100k = CN_u \qquad (10)$$

The expression 100k might be thought of as the "ultimate curve number" or the curve number at infinite precipitation. It is obvious from the above paragraphs and from Table 2 that k (or 100k) is a much more stable index of storm watershed performance than the raw CN as used, or as derived from equations (7) and (6).

Table 1

Watershed and Storm Runoff Information

ID No.	Name (DA:Ac)	Location	#Storms	Precip. $\bar{P}$	Precip. S	Runoff $\bar{Q}$	Runoff S	Data Source
1	Halfway Cr (464)	Utah	14	0.88	0.41	8.22	7.0	3
2	Morris Cr (156)	Utah	17	0.82	0.35	2.51	1.72	3
3	Alpine Meadows (376)	Utah	10	0.56	0.26	36.8	28.9	3
4	Missouri Gulch (4200)	Colorado	14	0.60	0.36	1.87	1.44	1

All Precipitation in inches. All runoff in 0.001 inches.

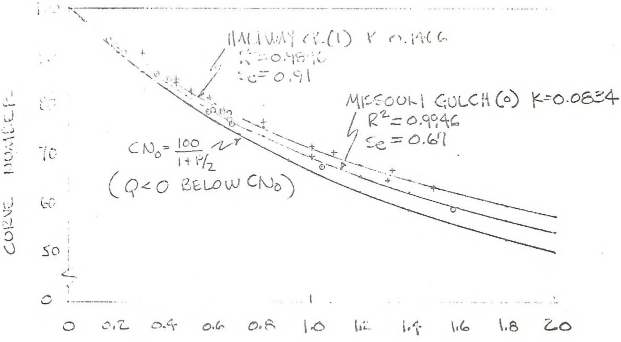
Table 2

Statistical Data--Curve Numbers

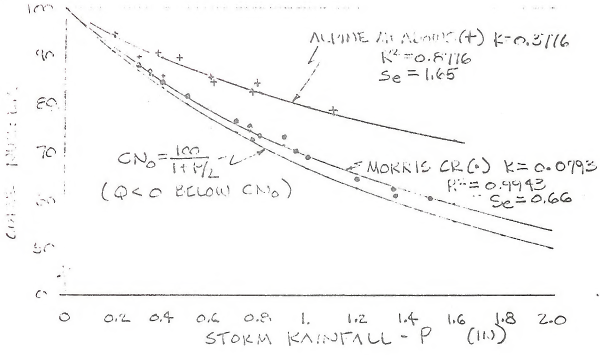
WS	$\overline{CN}$ 1/	S_{CN} 2/	k 3/	r^2 4/	Se 5/
1	75.29	8.89	0.1466	0.9896	0.908
2	74.37	8.69	0.07933	0.9943	0.657
3	86.59	4.36	0.3776	0.8776	1.649
4	80.20	9.03	0.08339	0.9946	0.669

1/, 2/. From basic P-Q data. Mean Curve Number and standard deviation

3/, 4/, 5/. Results of curve fitting individual CN's to P according to eq 5, 9 by least squares.



Se = 0.91
MISSOURI GULCH (o) K=0.0834
R² = 0.9946
Se = 0.67
CN₀ = 100 / 1+P/2
(Q<0 BELOW CN₀)



Se = 1.65
CN₀ = 100 / 1+P/2
(Q<0 BELOW CN₀)
MORRIS CR (•) K = 0.0793
R² = 0.9943
Se = 0.66
STORM RAINFALL - P (IN)

Thus watershed condition and runoff capability might be more adequately described in terms of "ultimate curve number." Any use of CN in the existing methodology assumes a certain P associated with it, either consciously or implied. The modification suggested can be reduced to a change in the definition of S from

$$S = \frac{1000}{CN} - 10 \text{ (a form of (6))} \tag{11}$$

to

$$S = 10\left[\frac{P(1 - k)}{2 + kP}\right], \tag{12}$$

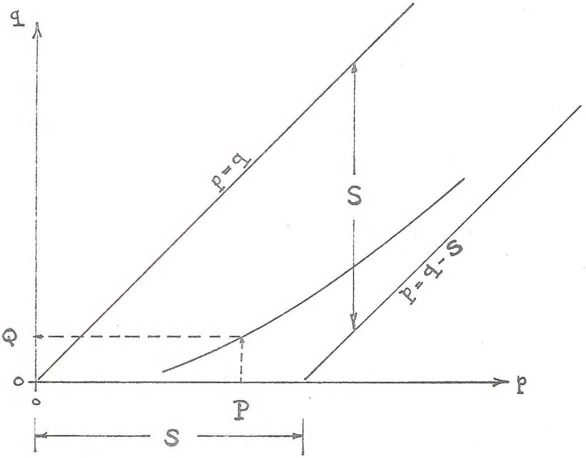
which is derived by substitution of (9) into (11). This change, in fact, eliminates the use of CN and substitutes k (or 100k) for it, as a more stable and meaningful parameter.

V. Discussion and Conclusions

The above exposition suggests that the curve number system as practiced and defined by SCS procedures does not match reality. The curve number, supposedly a constant watershed parameter, is shown to be highly dependent upon storm size.

Several avenues of explanation can be explored. First, an obvious argument is that the watershed does not function as assumed in the derivation of the SCS runoff equation. That is, the original proportion (Equation 1) is not entirely valid, and the assumption of $I_a = 0.2S$ as an approximation is incorrect. Secondly, and similarly, there are hydrologic processes omitted from the derivation which are important in wildland hydrology. Prominent among these omitted processes is direct channel interception. The low runoff values experienced suggest this was a primary source of streamflow for the situations studied. Other studies (not covered herein) on rangeland plots without channels show a similar retreating CN-storm size relationship, although the fit is not nearly as precise. These experiences reinforce the channel interception hypothesis.

Third, it can be argued, that the storms studied were not big enough to fully develop the hydrologic relation implied with the curve number technique and that the actual streamflow experienced represents a collection of hydrologic odds-and-ends. However, this contention can be rebutted on two grounds: 1) the sample period in each case covered a period of about twenty years, which should be sufficient to expect at least one "normal" design occurrence; and 2) if this is a good argument, it is also an admission that the curve number technique does not reproduce reality and, thus, new approaches are justified for these situations.



q
p=q
S
p=q-S
Q
0
0
p
P
S

Symbols

CN: Curve Number

CN_o: Curve Number at Q = 0. Equal to 100/(1 + P/2).

CN_p: Curve Number for a given P and Q.

CN_u: Ultimate Curve Number, envisioned as $P \rightarrow \infty$.

I_a : Initial Abstraction: the rainfall abstraction prior to initiation of runoff (in.).

k: A runoff coefficient characteristic of the watershed.

p,P: Storm rainfall (in.).

q,Q: Storm hydrograph runoff (in.).

S: Maximum possible difference between rainfall and runoff (in.).

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2. USDA, Soil Conservation Service. 1969. National Engineering Handbook, Section 4, Hydrology.

3. Walker, Clive H. 1970. Estimating Rainfall-Runoff Characteristics of Selected Small Utah Watersheds. M.S. Thesis, Utah State University. 120p.

Appendix 2

<u>Runoff Curve Numbers</u>

Milford 7-30-68

Windrow Treatment

Plot	P	Q	CN
1	1.65	1.51	98.8
2	1.65	1.53	99.0
3	1.65	1.45	98.2
4	1.65	0.72	88.5
5	1.65	1.15	95.0

Control

Plot	P	Q	CN
1	1.65	0.35	79.6
2	1.65	1.21	95.7
3	1.65	1.40	97.7
4	1.65	0.54	84.8
5	1.65	0.35	79.6

Milford 7-31-68

Windrow Treatment

Plot	P	Q	CN
1	.60	.30	96.3
2	.60	.39	97.3
3	.60	.13	91.6
4	.60	.05	87.0
5	.60	.09	89.7

Control

Plot	P	Q	CN
1	.60	.09	89.7
2	.60	.29	96.1
3	.60	.08	89.1
4	.60	.11	90.7
5	.60	.05	87.0

Milford 8-8-68

Windrow Treatment

Plot	P	Q	CN
1	.70	.15	90.3
2	.70	.17	91.0
3	.70	.02	80.9
4	.70	.02	80.9
5	.70	0	0

Control

Plot	P	Q	CN
1	.70	.06	85.2
2	.70	.05	84.4
3	.70	.01	79.0
4	.70	0	0
5	.70	0	0

Milford 9-5-70

Windrow Treatment

Plot	P	Q	CN
1	1.47	.12	73.0
2	1.47	.11	72.4
3	1.47	.12	73.0
4	1.47	.05	67.7
5	1.47	.18	76.2

Control

Plot	P	Q	CN
1	1.47	.07	69.5
2	1.47	.05	67.7
3	1.47	.12	73.0
4	1.47	.09	71.0
5	1.47	.04	66.6

Debris-in-Place

Plot	P	Q	CN
1	1.47	0	0
2	1.47	0	0
3	1.47	.08	70.3
4	1.47	.03	65.4
5	1.47	0	0

Control

Plot	P	Q	CN
1	1.47	.04	66.6
2	1.47	.05	67.7
3	1.47	.14	74.1
4	1.47	0	0
5	1.47	.12	73.0

Blanding 7-28-68

Windrow Treatment

Plot	P	Q	CN
1	.45	.02	87.9
2	.45	.16	95.7
3	.45	.02	87.9
4	.45	.13	94.8
5	.45	.02	87.9

Note --- No runoff from debris-in-place

Control

Plot	P	Q	CN
1	.45	.01	86.3
2	.45	.05	90.9
3	.45	.01	86.3
4	.45	.01	86.3
5	.45	.01	86.3

Blanding 7-30-68

Windrow Treatment

Plot	P	Q	CN
1	0.45	.07	92.2
2	0.45	.14	95.1
3	0.45	.07	92.2
4	0.45	.13	94.8
5	0.45	.05	90.9

Note --- No runoff from debris-in-place

Control

Plot	P	Q	CN
1	0.45	.04	90.1
2	0.45	.03	89.2
3	0.45	.03	89.2
4	0.45	.03	89.2
5	0.45	.03	89.2

Blanding 8-5-68

Windrow Treatment

Plot	P	Q	CN
1	1.45	.68	90.7
2	1.45	.50	87.0
3	1.45	.63	89.7
4	1.45	.52	87.4
5	1.45	.29	81.0

Control

Plot	P	Q	CN
1	1.45	.42	85.0
2	1.45	.47	86.3
3	1.45	.72	91.4
4	1.45	.34	82.7
5	1.45	.16	75.6

Debris-in-Place

Plot	P	Q	CN
1	1.45	.09	71.4
2	1.45	.13	73.9
3	1.45	.25	79.6
4	1.45	.09	71.4
5	1.45	.16	75.6

Control

Plot	P	Q	CN
1	1.45	.24	79.2
2	1.45	.66	90.3
3	1.45	.25	79.6
4	1.45	.30	81.4
5	1.45	.15	75.0

Blanding 8-3-70

Windrow Treatment

Plot	P	Q	CN
1	1.27	0.32	85.2
2	1.27	0.36	86.4
3	1.27	0.07	73.3
4	1.27	0.28	83.9
5	1.27	0.21	81.3

Control

Plot	P	Q	CN
1	1.27	0.05	71.5
2	1.27	0.03	69.2
3	1.27	0.03	69.2
4	1.27	0.05	71.5
5	1.27	0.07	73.3

Debris-in-Place

Plot	P	Q	CN
1	1.17	0	0
2	1.17	0	0
3	1.17	0	0
4	1.17	0	0
5	1.17	0	0

Control

Plot	P	Q	CN
1	1.17	0	0
2	1.17	0	0
3	1.17	.05	73.5
4	1.17	.04	72.5
5	1.17	0	0

Blanding 8-4-70

Windrow Treatment

Plot	P	Q	CN
1	0.81	0.54	97.1
2	0.81	0.64	98.4
3	0.81	0.10	85.4
4	0.81	0.34	93.7
5	0.81	0.23	90.9

Control

Plot	P	Q	CN
1	0.81	0.15	87.9
2	0.81	0.10	85.4
3	0.81	0.14	87.5
4	0.81	0.11	85.9
5	0.81	0.10	85.4

Debris-in-Place

Plot	P	Q	CN
1	0.72	0	0
2	0.72	.08	86.2
3	0.72	0	0
4	0.72	0	0
5	0.72	.04	82.9

Control

Plot	P	Q	CN
1	0.72	0	0
2	0.72	.03	81.8
3	0.72	.04	82.9
4	0.72	.11	88.0
5	0.72	.03	81.8

Blanding 8-16-70

Windrow Treatment

Plot	P	Q	CN
1	1.00	0.35	90.8
2	1.00	0.32	90.0
3	1.00	0.29	89.1
4	1.00	0.21	86.5
5	1.00	0.18	85.3

Control

Plot	P	Q	CN
1	1.00	0.12	82.3
2	1.00	0.19	85.7
3	1.00	0.24	87.6
4	1.00	0.12	82.3
5	1.00	0.10	81.1

Debris-in-Place

Plot	P	Q	CN
1	0.76	0	0
2	0.76	0	0
3	0.76	0	0
4	0.76	0	0
5	0.76	0	0

Control

Plot	P	Q	CN
1	0.76	.07	84.5
2	0.76	0	0
3	0.76	.08	85.3
4	0.76	0	0
5	0.76	.03	80.7

Blanding 8-19-70

Windrow Treatment

Plot	P	Q	CN
1	0.75	0.52	97.6
2	0.76	0.27	93.1
3	0.75	0.35	94.9
4	0.75	0.24	92.3
5	0.75	0.23	92.0

Control

Plot	P	Q	CN
1	0.75	0.13	88.3
2	0.75	0.18	90.4
3	0.75	0.16	89.6
4	0.75	0.18	90.4
5	0.75	0.17	90.0

Debris-in-Place

Plot	P	Q	CN
1	0.69	0	0
2	0.69	.04	83.7
3	0.69	0	0
4	0.69	.01	79.3
5	0.69	.05	84.6

Control

Plot	P	Q	CN
1	0.69	.06	85.5
2	0.69	.03	82.6
3	0.69	0	0
4	0.69	.05	84.6
5	0.69	.03	82.6